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Orbit Analysis Tools Software (Version 3) Users Manual

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The Orbit Analysis Tools Software (OATS) program has been expanded. The program's function is to perform satellite mission and coverage analysis using numerical and graphical techniques to analyze and display earth coverage data and ground to satellite geometrical parameters. Satellite ephemerides can be computed by any one of four orbit propagators provided with the program or imported from an external source. Program enhancements include addition of another orbit propagator, another map projection, and the use of color plotting, as well as display or orbit coverage using density contouring and a swath display function. The program is written in FORTRAN utilizing the FACEIT program interface software. OATS is designed to run on a Macintosh personal computer.

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ORBIT ANALYSIS TOOLS SOFTWARE (VERSION 3) USERS MANUAL

SECTION 1 - INTRODUCTION

This document provides a user's manual for the Orbit Analysis Tools Software (OATS) program. OATS is a mission planning and analysis tool for Earth-orbiting satellites. OATS evolved from a collection of software tools developed by the Astrodynamics and Space Applications Office of the Naval Center for Space Technology, located at the Naval Research Laboratory in Washington, DC. It is a single new integrated program that runs on a Macintosh computer. OATS provides a graphics-oriented analytical environment that can be used to address many of the questions commonly posed by designers planning a new satellite system or by managers wishing to assess the performance of an existing system. OATS particular strength is the quantification of satellite coverage available from a user-defined configuration of satellites.

This manual is intended to provide an overview of OATS that will permit potential users to determine if the program meets their analytical needs. It discusses all program functions, shows how to access the various capabilities of OATS, and presents what the user should expect to see when the program menus and options are exercised. To complement its overview function, this manual is organized to provide fast access to information on single program capabilities. OATS is user-friendly in the accepted Macintosh fashion and some users may not require documentation; however, this manual will provide fast access to many of the details of program operation and will discuss strategies for efficient use of the program.

OATS major analytical capabilities and outputs include:

- Computation of pass parameters for a satellite and ground station, including azimuth, elevation, range, and range rate as a function of time, the times of acquisition of signal (AOS) and loss of Signal (LOS), and signal attenuation.
- Computation of coverage statistics for a set of targets under a system of nadir-pointing satellites using an optional set of ground stations for communication links. Statistics include rise and set times, duration of coverage, outage, and revisit times, and maximum, minimum, mean, and standard deviation of coverage, outage, and revisit times.
- Computation and display for a system of satellites and ground stations of coverage data on a global grid. Display can be as a contour mapping of coverage isochrones or as a density mapping of regions of equal coverage.
- Creation of global maps, using a selection of two- and three-dimensional map projections.
- Creation of satellite ephemeris data, using a selection from four different orbit propagators.
- Display satellite geographic data, including position, field-of-view (FOV), ground tracks, and coverage swaths.

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- Display ground geographic data, including target and ground station positions, ground station fields-of-view (FOV), and Earth shadow data.
- Display of all mapped data with user-controlled colors, line widths, shading densities, and icon sizes.

Users should be aware that OATS employs the FACEIT software (Reference 1) to build its fundamental working Macintosh foundation. FACEIT provides all the basic types of environmental elements like graphics display windows, dialogs, and editors, as well as a fast, clean interface to most Macintosh toolbox utilities. All the expected Macintosh capabilities are made immediately available, such as the ability to cut and paste OATS analytical and graphical outputs into other Macintosh applications. This is a tremendous boost in getting a functional program up and running quickly. FACEIT allows the programmer to concentrate on the analytical functions rather than dealing with the exacting details of Macintosh programming. However, the use of FACEIT does introduce a few oddities into the OATS software. The programmer forfeits some control of menus and windows in exchange for ease in constructing the program and building interfaces. This is not a serious problem, but at times there are incongruities or a lack of spontaneity in execution. In most cases users will not notice FACEIT at all.

This manual will presume familiarity with basic Macintosh operations, including features like use of the mouse, selecting program functions with menus, setting program parameters and options with dialogs, and the standard Macintosh file interface dialogs. Users should also bear in mind that in typical Macintosh fashion OATS provides a working environment with a multitude of choices and analytical pathways, rather than a linear program with a narrow and well-defined set of inputs and outputs.

Section 2 provides information about the software distribution diskette and operating requirements. Section 3 is an overview of the OATS system and Section 4 discusses the design philosophies behind OATS. Both of these sections are general, high-level views of OATS' conventions, capabilities, and operating environment. Section 5 contains a discussion of all menu commands used to control and change the OATS operating environment, including window control parameters and printing. Section 6 explains the use of each of the orbit propagators and the generation of ephemeris data. Section 7 is a lengthy chapter because it discusses in detail the many plotting functions available to OATS users. Much of the program's analytical techniques are explained in Section 8, which shows how to perform the various satellite coverage analyses. Section 9 discusses the opening and inspection of ephemeris files, which are required for most of the analysis available through OATS. Section 10 discusses the format of self-generated and external files. Section 11 is the last chapter--it presents a sample introductory session that can be used as a quick-start training exercise for beginning users. Three appendices provide supplemental information. The satellite antenna pattern definitions are contained in Appendix A. Appendix B contains helpful tips

regarding processing of data with OATS, and Appendix C provides a review of the definition of orbital elements.

SECTION 2 - DISTRIBUTION DISKETTE

OATS runs on a Macintosh computer with a math co-processor under System 6 or System 7. The OATS executable program and related files are contained on a single high density 3.5 inch diskette, which may be obtained from the authors. Versions of the software have been created to run with the Macintosh 88030 and 88040 central processor units (CPU), and interested users should specify which CPU they will be using to run OATS when they request a copy of the software.

OATS requires two megabytes of memory for minimal function; however, many of the graphics procedures require added memory. Experience has shown that OATS runs more efficiently if four or five megabytes of memory is made available. No additional files beyond the executable are required to run OATS; however, five data files are provided to assist the beginning user in gaining familiarity with OATS. The use and content of these files is discussed in Section 11, which provides a quick-start training exercise on the use of some of the major features of OATS.

SECTION 3 - OVERVIEW OF THE OATS SYSTEM

This section presents an overview of the OATS software. It discusses windows used by the program, the OATS high level menu system, menu display conventions, dialog display conventions used in this manual, and a review of the utility dialogs used by OATS. Detailed information on the various menu options and dialogs available through OATS can be found later in this manual in Sections 5 through 9.

3.1 OATS WINDOWS

OATS utilizes four work windows, the controls for which are discussed in Section 5.4. These windows include:

- Graphics Window - Due to the graphics-oriented approach of the OATS program, this window is probably the most important. It is also the window which is most commonly elected to be the default window viewed when the program is initiated. This is a full-view unity-scale graphics window used for all OATS mapping, orbit plotting, and coverage contouring activities. It should be thought of as the local active drawing window, even though it may not show all objects in the plotting region. FACEIT provides a single drawing area (i.e. plotting region) which has maximum dimensions of 30,000 by 30,000 pixels, and which can be divided into many pages as required. Very few OATS problems would ever require such a large drawing area, and seldom is more than one page needed. Most commonly the drawing area, the Graphics Window, and the screen size are equivalent and are set to dimensions that are a few hundred pixels on a side and are undivided (i.e. single page). However, there may be some circumstances where OATS will employ a drawing area that measures a few thousand pixels on a side (for example, see Appendix B). Since the typical Graph Window must still conform to screen dimensions that are a few hundred pixels on a side, only a modest percentage of the drawing area would be visible at any given time.
- Tabular Window - This is an editor-type window. This window is primarily used for immediate display of tabular data during its generation by OATS analytical functions, even though the user can perform many of the standard types of functions common to editors for data displayed in this window (e.g. search for text strings or print selected sections). It is possible to use this window as a text editor; however, it is only prudent to do so for small items and to avoid the task of opening an external editor or switching back and forth between OATS and another editor.
- Reduced View - This is a reduced-view window that echoes the Graphics Window; however, at a significantly smaller scale so that the entire plotting area is visible. Its function is most helpful if the user elects to use multi-paging of plots where not all plotted data is visible in the Graphics Window. This window cannot be resized, and the reduction ratio is shown in the window's title bar at the top.

- Utility Text Entry Window - This is also an editor-type window, used where OATS has supplemental requirements for text entry and/or display. It is used with the Inspect Ephemeris File function for display of file data (see Section 9.2) and with some dialogs that provide the user the capability to directly enter satellite ephemeris data in native format (see Section 6.3).

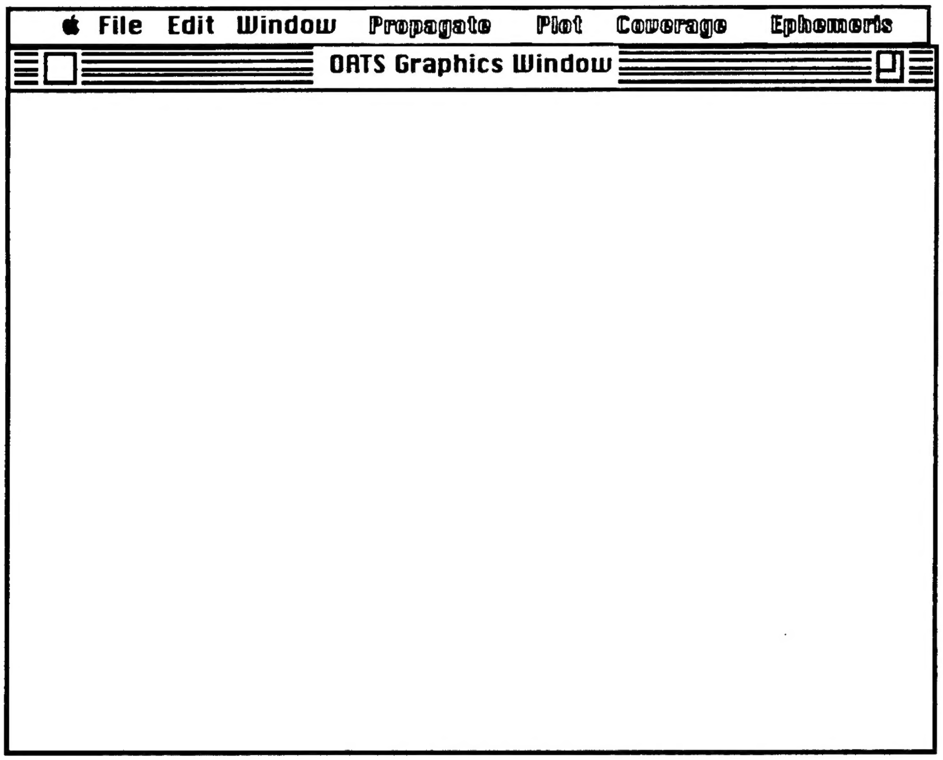

Figure 3-1. OATS Main Menu

3.2 OATS MAIN MENU

Figure 3-1 shows the OATS Main Menu along with the OATS Graphics Window as they might appear when the program is initiated. OATS menu selections are broken into two groupings. The first group is covered in Section 5, and includes all menu items geared toward control and definition of the OATS operating environment. These menu items include:

- **Apple** () - Provides access to overview functions associated with OATS.
- **File** - Provides functions used to manipulate files associated with OATS.
- **Edit** - Provides most normal Macintosh editing functions, some of which are applicable to graphics windows as well as to the editor windows.
- **Window** - Provides controls for manipulation of and definition of windows used by OATS.

The second group is covered in Sections 6 through 9, and includes the analysis tools used by OATS to perform orbit and satellite coverage analysis. Note that these menu options will appear as a different color than the environment options. These menu items include:

- **Propagate** - Provides functions required to generate ephemeris files, including access to and display of orbital elements.
- **Plot** - A large menu system that gives the user the ability to define and execute graphics plots of satellite orbits and coverage information.
- **Coverage** - Provides access to the analytical tools that generate information related to satellite coverage and visibility.
- **Ephemeris** - Provides functions required to open existing ephemeris files for use by OATS processes or to preview existing ephemeris files.

3.3 MENU DISPLAY CONVENTIONS

As is common in Macintosh applications programs, selection of any of the menu items shown in Figure 3-1 will yield an additional list of menu items--some of which themselves will also yield sub-menu lists. In this manual, the conventions used to show the result of selection of a menu item are characterized in the sample menu shown in Figure 3-2. As shown in this sample:

- **OptionA. . .** — shows a dialog used to set execution parameters
- **OptionB** ▶ — produces a sub-menu of choices
- **ActionA** — executes a process
- **ActionB** **⌘X** — executes a process, which can also be executed without using the menu system by entering the **⌘-X** command-key

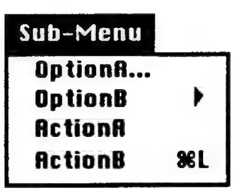

Figure 3-2. Sample Menu Display

3.4 DIALOG DISPLAY CONVENTIONS

Figure 3-3 presents a representative OATS dialog. Dialogs in this program utilize most of the standard tools available in Macintosh user interfaces, such as command buttons, static text and static pictures, on/off checkboxes, mutually exclusive radio buttons, and control scroll bars to allow selection of a value on a scale between fixed endpoints. Whenever any such item in a dialog is mentioned specifically in the text of this document, the convention will be to italicize the item (e.g. *Standard Macintosh Checkbox*) to make clear that an individual dialog item is being singled out.

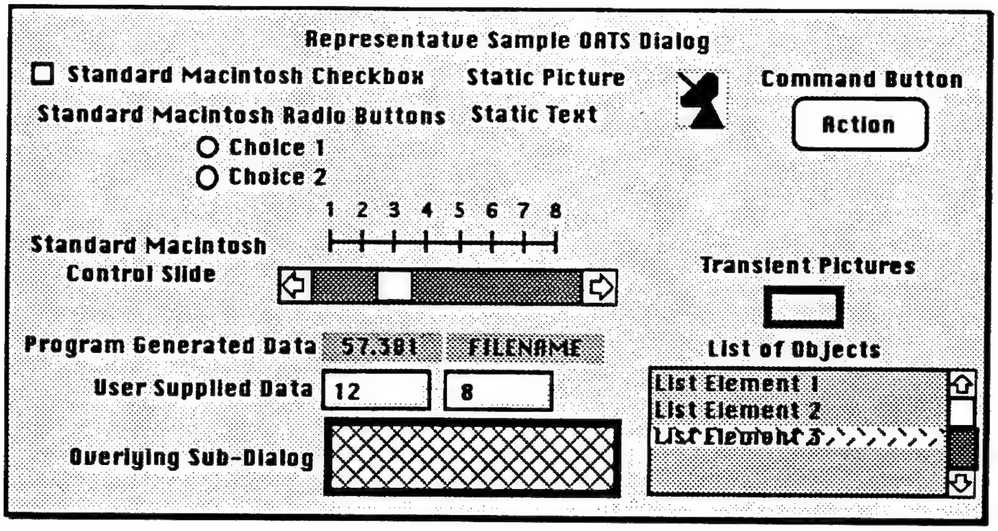

Figure 3-3. Sample Dialog Display

There are several dialog display devices that are peculiar to this manual, and which are also shown in Figure 3-3. These include:

- Program Generated Data - These fields show locations where OATS will provide information to the user, and for which the program has control of what is displayed. Dialogs are shown with a representative value in place in these fields. Actual displays will of course depend on the various program settings elected by the user.
- User Supplied Data - These fields allow data to be entered by the user. Typically the program will supply some type of default or previously assigned data. The user's data is entered by using the mouse or the **TAB** key to place the cursor in the desired field before typing in data. OATS displays of this type will contain a number for both numerical entries and for text entries indicating the maximum number of characters which the user can enter into this field.
- Overlying Sub-Dialogs - In a few cases, overlying dialogs are used such that a small dialog is used to enter data complementary to the large dialog interface upon which it is shown superimposed. The location of the overlying dialogs is shown by a hatched rectangle.
- Lists of Objects - These are also shown with a few representative elements in place. In cases where some other aspect of the dialog is directly dependent on which member of the list is selected, a member of the list is shown highlighted.
- Transient Pictures - In a few cases, transient pictures are drawn within dialogs. The locations of these items are shown in the dialog in which they are drawn.

3.5 UTILITY MENUS

There are several utility dialogs used throughout OATS. The first is shown in Figure 3-4, and is displayed when the user elects to overwrite an existing file. Possible cases of file overwrite by OATS are flagged for the user with this dialog, which presents the *File* name and allows the user to *Proceed* with the file overwrite or to *Cancel* the operation and return to the main menu.

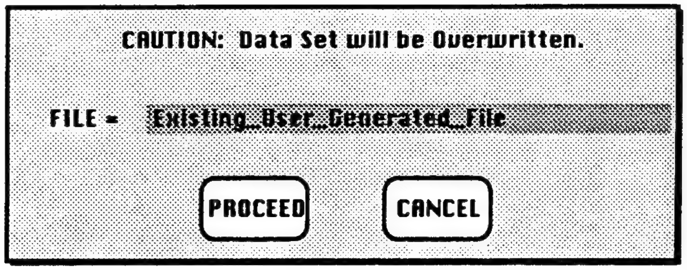

Figure 3-4. Data Set Protection Dialog

OATS makes extensive use of color in its plotting routines. Figure 3-5 is used to allow the user to set the color employed by all line plot functions and for some area plot functions. This dialog presents a short title for the information in question, and a small *Color* swatch of the current color setting. The user may reset the color in three ways. The first is to use one of the eight standard QuickDraw colors (Reference 2) using the radio button controls. The second is to use the color look-up table shown here by a grid patch. By clicking and holding the mouse on this area, an expanded view of the 256 available colors is presented--one of which can be singled out with the mouse. If this option is used, the color settings retained by OATS will be exactly that which is selected. The third way is to use the color *Picker* button, which presents the standard Macintosh Color Picker Dialog Box (Reference 3). The Picker dialog presents a color wheel, a brightness scroll bar, and numerical color settings that can be used to set any color. The user should note that although the Picker is an easy way to set colors, any color set using the Picker will be rounded to whichever of the 256 in the look-up table is closest. As usual, the *Cancel* button will nullify any color settings changed in this dialog and the *Set* button will retain them for OATS plotting functions. All color settings are saved between OATS executions.

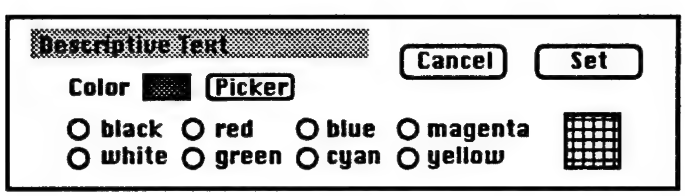

Figure 3-5. Utility Dialog for Color Selection

The appearance of plotted text in OATS is controlled with dialogs like that seen in Figure 3-6. Note that the top of this dialog is exactly like Figure 3-5, and is used in exactly the same way. With the remainder of this dialog the *Font* can be reassigned by clicking on any of those available in the list, the text *Size* can be set to the desired numerical size, and the text style can be selected by setting one of or a combination of *Style* checkboxes. These checkboxes are a standard set; however, note that in most cases the *Underline* style has been disabled for OATS. This print style tends to interfere with plot clarity. Again, the *Cancel* button will nullify any color settings changed in this dialog and the *Set* button will retain them for OATS plotting functions. All font settings are saved between program executions.

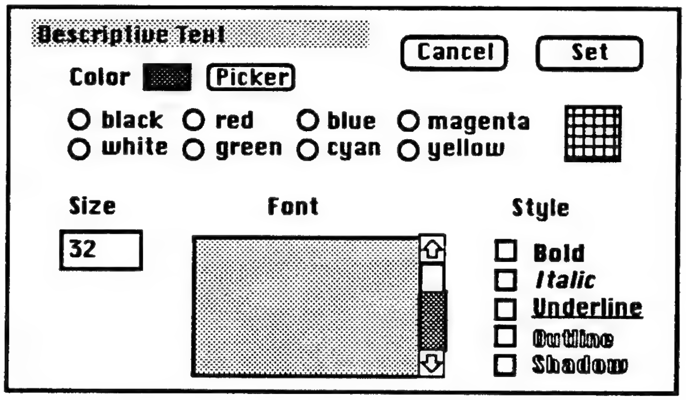

Figure 3-6. Utility Dialog for Font Selection

SECTION 4 - PROGRAM DESIGN PHILOSOPHIES

Every piece of software comes with some set of inherent design philosophies and approaches to problems. In principle these design issues should be transparent to the user as much as possible, but in practice some aspects of program construction will show through. OATS is no different. This section presents a collection of design issues which impact on how the user approaches execution of the software. It would be helpful to keep these issues in mind when using the program.

4.1 IMPORTANCE OF EPHEMERIS FILES

The OATS program combines orbit propagation models with numerical and graphical coverage analysis algorithms. The design philosophy of OATS has been to separate the orbit models from the analysis processes. The reason for selecting this architecture is so that an arbitrary number of different orbit propagation codes can be added to the program without affecting any of the analysis codes. Thus, when doing mission analysis with OATS the user must always have satellite ephemerides available before proceeding with any of the coverage analysis functions. OATS is engineered to generate ephemeris files using a variety of orbit propagation models, and it is expected that a typical user will employ the OATS orbit propagators to generate ephemerides prior to performing analysis; however, OATS is also capable of employing imported ephemeris files if they use a prescribed format. The only difference between use of internally generated ephemeris files and exported ones is that processing will be slightly faster for the internally generated files.

4.2 LAYERING

When OATS creates graphics plots, it uses a layering technique similar to such programs as MacDraw II (Reference 4). For example, a map drawing (see Section 7.3) can consist of as many as five layers of drawings which are then "glued" together into a single layer. The user should be aware that under some circumstances plotted items can be immediately erased from the drawing without impacting other previous layers in the drawing; however, other circumstances dictate the opposite situation. As examples, consider that a plot of a list of targets (see Section 7.2.5) is a single layer that can be removed and re-drawn as often as needed to get it correct if the corrections are made consecutively. On the other hand, if a zoom process is exercised (see Section 7.4.1) it is necessary to "cement" all plotted layers together. This implies that if the layer of plotted targets is in error, the entire plot must be redone to correct the problem. The layering approach also implies that layers can be moved forward and backwards under some circumstances. One of the ramifications of the layering approach is seen whenever it is necessary to reconstruct the screen, for instance when a dialog is temporarily shown over top of the graphics window. The screen is re-drawn one

layer at a time. If there are many layers, this can become time consuming; however, it is possible to circumvent the problem by manually cementing multiple layers into a single layer (see Section 5.3).

4.3 DATA CHECKING

OATS performs checks of entered data; however, modifications to the user entered data by the program are minimal. Unusual entries are flagged and an ALERT is displayed, but usually no attempt is made to alter or "fix" the data. In the isolated cases where OATS tries to implement a "fix", the user is conspicuously notified. Otherwise, any unusual data entries are carried along after an ALERT is given. It is the obligation of the user to correct them. Choosing to ignore an ALERT will at the very least cause generation of incorrect or invalid data. At the worst, it can cause a program crash.

4.4 WORK FILES

OATS uses scratch space work files for some processes. During the course of a normal program execution, these files are deleted and the user doesn't see them or have to deal with them. Abnormal endings of program execution may imply leftover files that the user may wish to delete. These files can be identified because they are created in the directory from which OATS is launched and bear a "TEMP." prefix. If space is severely restricted on the user's computer, there may also be system generated error conditions if the scratch files overflow storage capacity.

4.5 USE OF THE MARQUEE

OATS draws plots in the Graphics Window within a highlighted marquee, a rectangular area with a moving dotted line defining its edge. While it is common to allow the marquee region to be defined by the full open Graphics Window (default plotting area), plots can be made in subsets of the Graphics Window by defining a reduced marquee. The marquee is most easily defined in an empty Graphics Window by clicking and dragging the mouse to the desired size. If some figures exist in the window, the command key (⌘) key must be pressed and held while clicking and dragging. The command key is also often known as the Apple () key. This marquee can be used, for example, to define multiple plots side-by-side for comparison purposes. It is also possible to define the marquee within the Reduced View Window in a similar fashion, because the marquee will be echoed in the Graphics Window. Although OATS users will not typically make use of the capability, FACEIT makes it possible to define an n-by-m multi-page drawing area (see Section 5.4). All pages are shown in the Reduced View Window. Using the marquee also allows plots to be defined across page boundaries.

4.6 FACEIT RELATED INCONGRUITIES

FACEIT (see Section 1) tries to cater to a wide variety of types of programs needing Macintosh interfacing. In general, it works quite well, but by using FACEIT the programmer forfeits some control of menus and windows in exchange for ease in constructing the program and building interfaces. There are no serious problems that result from this forfeiture of programming controls, but there are a few oddities or an occasional lack of spontaneity in execution of the product software package. An effort has been made to remove these anachronisms, but a few remain. As an example, sometimes use of the Color Picker Package will cause the dialog list element highlight color to be altered.

SECTION 5 - ENVIRONMENT MENUS

This section describes the behavior and performance of the OATS menu items that deal with the system's operating environment. The relationship of these menu selections to the OATS system menu were briefly described in Section 3.2. These selections include those which are largely under the control of the FACEIT utility, and which have direct counterparts in most Macintosh-styled software. For OATS, this complement of environment menus includes the **Apple**, **File**, **Edit**, and **Window** main menu selections. A characteristic of many of the environment menus to which the user should pay special attention is that they change depending upon whether a graphics-type window or an editor-type window (see Section 3.1) is the window in front. The front window is referred to as the active display.

5.1 APPLE MENU

Figure 5-1 shows the sub-menu produced by choosing the **Apple** () menu. These menu selections deal with program overview functions and with parameters that affect the full OATS program.

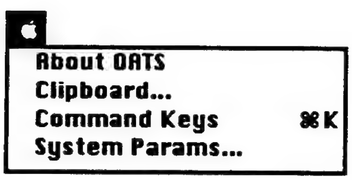

Figure 5-1. **Apple** Menu for OATS

About OATS

This command produces an informational display similar to that seen in Figure 5-2. It provides information such as program authors and address, but most importantly it provides the version number and date for this copy of OATS. This display is exited by clicking inside the informational box near the top of the display.

Clipboard

This command shows the user the current contents of the clipboard, in a display similar to that seen in Figure 5-3. The large clip-window (empty in the example shown) may contain text or graphics. A summary of the memory tied up in the clipboard, in text windows, and in graphics windows is shown to the side. This selection is most useful as a means of verifying information that is being imported into of out of OATS. An option *Clear* button allows the user to clear the contents of the clipboard. The number in the upper right corner is the FACEIT version used when compiling OATS. This display is exited by clicking inside the box for the large clip-window.

Command Keys

This command produces an informational display similar to that seen in Figure 5-4. Like most Macintosh programs, OATS allows the use of two-stroke command-key sequences to produce the

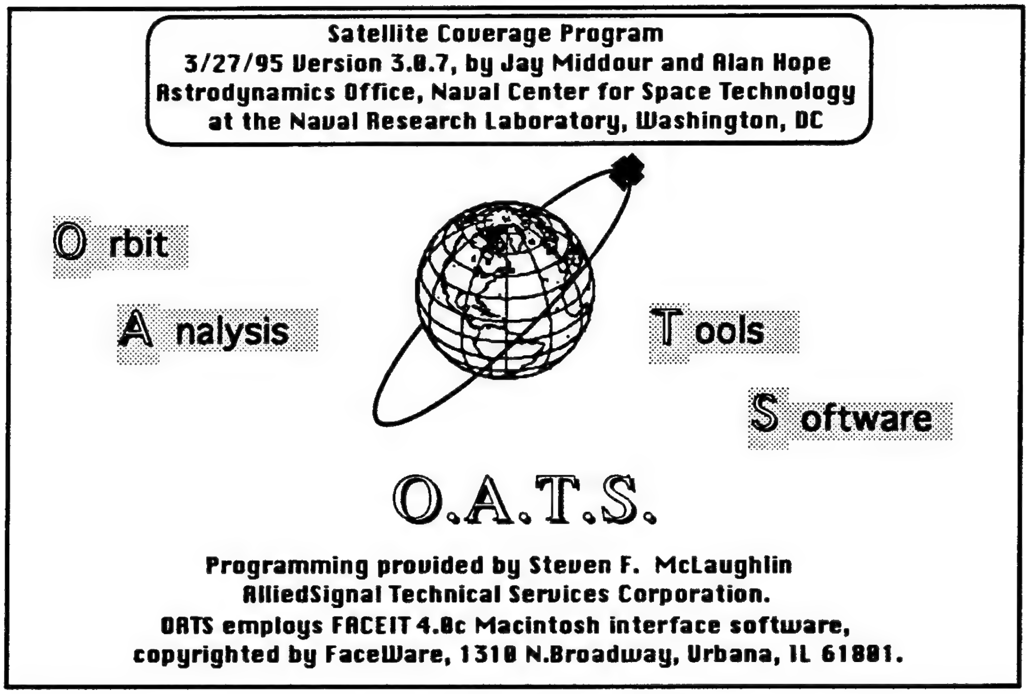

Figure 5-2. Informational Dialog on OATS

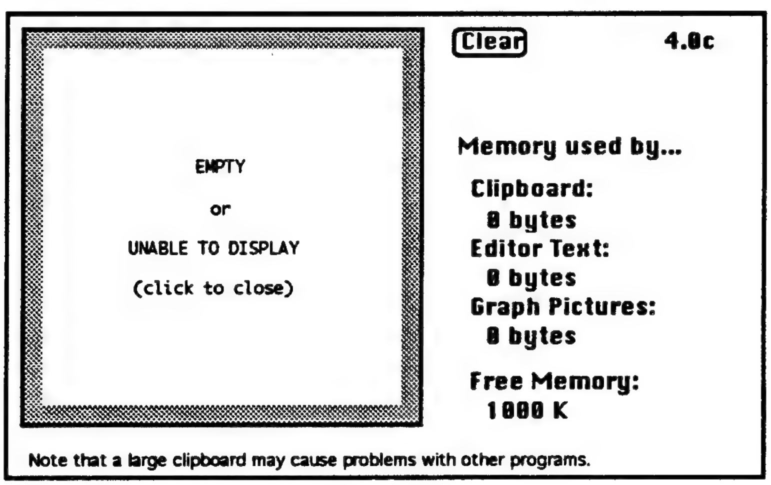

Figure 5-3. Clipboard Dialog in OATS

same results as some of the high-use menu selections. This display presents a single-glance review of the available command-key sequences for OATS. The display is itself available with the use of a **⌘-K** command. A few command-key sequences change according to the window

which is currently foremost in the screen display. These dual-effect commands are shown with a slash separating the two functions, and with the graphics mode action first and the text mode action following. All command-keys will be noted in later sections of this document.

Numerical Keys - Plot Items on Map

1 : Satellite Field-of-View
2 : Satellite Tracks
3 : Satellite Position
4 : Satellite Swath
5 : Target Positions
6 : Ground Station Positions
7 : Ground Station Field-of-View
8 : Density Contours
9 : Line Contours
0 : Sun and Earth-Shadow Features

Letter Keys - OATS-Specific Commands

E : Ephemeris Files Open
I : Inspect Ephemeris Files
R : Run Propagator
M : Map Plot
W : Wipe Graphics Screen
L : Locator Mode
U : Zoom Up (Magnify)
D : Zoom Down (Shrink)
O : Original Size (Unzoom)
K : Key Commands (show this screen)

Letter Keys - FACEIT Commands

Q : Quit
P : Print
A : Select All
X : Cut
C : Copy
V : Paste
F : Bring to Front / Find
N : Send to Back / Next Case
Z : Undo Resize

"Slashed" Commands refer to Graphics Mode / Text Mode

Implement Commands from Menus or With " ⌘ - X " Keyboard Commands

Figure 5-4. Summary of All OATS Command-Keys

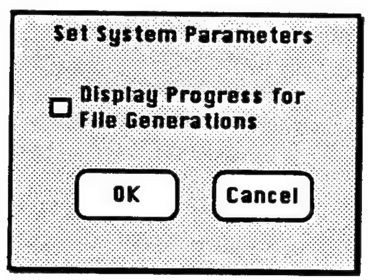

Figure 5-5. System Parameters Dialog

System Params...

This command provides a dialog as shown in Figure 5-5 that allows the user to set parameters that are used throughout the OATS analysis tools. There is currently only one parameter, an on/off flag controlling whether a status display of progress toward completion is presented when computations are being carried out. This display consists of a bar graph that grows in real time, plus a numerical percentage, plus the destination file name for the computation. There is some

quantity of overhead associated with generating this display. When the user is generating files that are small, the wait time is also small and the display can be turned off to bypass the overhead and facilitate program execution.

5.2 FILE MENU

The **File** menu as seen in Figure 5-6 provides functions used to manipulate files associated with OATS. Most of these options are analogous to their counterparts in other programs run on Macintosh computers.

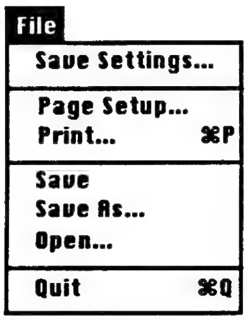

Figure 5-6. **File** Menu for OATS

Save Settings...

This command saves all window settings (see Section 5.4), most notably the size settings for the Graphics Window and the font size of the text windows. These settings are what will be used for the next OATS launch, even if window settings are changed (but not specifically saved) subsequent to issuing a **Save Settings** command. Any windows that are open when this command is issued will also be open when OATS is next initiated. The front-to-back order of open windows will also be maintained. More information on window settings is available in Section 5.4.

Page Setup...

The standard Macintosh **Page Setup** interface dialog is presented, which allows the user to chose the paper type, size, orientation, and special effects that will be used when printing.

Print...

The standard Macintosh **Print** interface dialog is presented, which allows the user to choose the number of copies, page limits, destination, etc. before printing the contents of the active window. As usual, the **Chooser** command under the **Apple** menu is used to select a printer and **Print** can be initiated with the command-key **⌘-P**.

Save

This command provides the option of saving the contents of the current front window, either graphics or text. If a previous save of the material has not been performed, the action will be the

same as for the **Save As** command. If the front window is empty, this option will become invalid (grayed out). OATS has program-specific icons that are used to save text and graphics files, as shown in Figure 5-7.

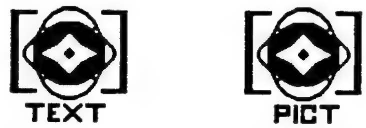

Figure 5-7. OATS Icons for Text and Graphics Files

Save As...

This commands brings up the standard Macintosh interface dialog used to select the directory and file name for a new file. If the graphics window is empty, this option is invalid. See also the discussion in Section 7.3 on saving Standard Maps. If multiple layers are plotted in the Graphics Window, they will be combined into a single picture before the save process is performed.

Open

The **Open** command is used to import picture files or text files into OATS, depending upon which window is foremost and active. If no window is open, this option is invalid. See also Section 7.3 on Standard Maps. **Open** is most useful for importing a foreign PICT file into the OATS Graphics Window to incorporate it as part of an OATS plot; however, an arbitrary text file can also be read into and edited using the Tabular Window.

Quit

This commands ends the OATS program execution. There is a brief delay before termination because OATS saves most current program parameter settings for the next execution. Only a few parameters are defaulted for each program run. Quit can be initiated with the command-key **⌘-Q**.

5.3 EDIT MENU

Edit provides most normal Macintosh editing functions, some of which are applicable to graphics windows as well as to the editor windows. The menu for the Tabular Window and Utility Text Entry Window (editor types) is shown in Figure 5-8. The equivalent menu for the Graphics Window is shown in Figure 5-9. Note that different options with the same command-keys will appear in the same menu position depending on the active window. The **Edit** menu also has one variation that will be discussed later in this section (see **Combine**) that depends on program status.

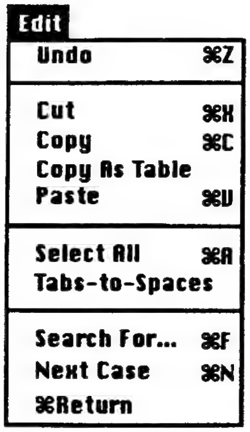

Figure 5-8. **Edit** Menu for OATS Tabular Windows

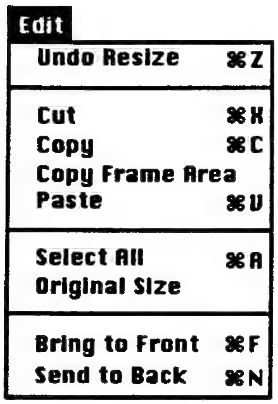

Figure 5-9. **Edit** Menu for OATS Graphics Window

Undo

This command is used to undo the previous editing action while using a text window. It is useful for correcting editing errors and can be initiated with the **⌘-Z** command-key.

Undo Resize

This command is used to restore a graphic to its original size after manually resizing the picture (see Section 5.5). This is also initiated with the **⌘-Z** command-key.

Cut

The **Cut** command (available as the **⌘-X** command-key) deletes an item which has been highlighted with the mouse for text data, or the top layer of the graphics display. The cut item is stored into the clipboard, from where it may be pasted into another application or into another area within the OATS window. Successive plotted layers may be removed by utilizing the **Cut** command, then clicking on the next layer, and then using **Cut** once again.

Copy

The **Copy** command creates a copy of the highlighted text item for an editor window or a copy of the top layer of the Graphics Window selected item and places it onto the clipboard. The copied data may then be pasted into another application, into another section of the drawing area in

OATS, or into another portion of the editor window. This can also be initiated with the **⌘-C** command-key.

Copy As Table

This command allows the user to select a portion of a text window and copy it to the clipboard. Each entry that is separated by one or more spaces is separated by a **TAB**. This formatting allows the data to be pasted directly into spreadsheet application software or onto another part of the text window.

Copy Frame Area

The **Copy Frame Area** command allows the user to select a subset of the window area using the marquee and to copy it to the clipboard. A marquee area is selected before issuing this command by pressing the **Apple** key and then click-and-dragging out the area that you wish to copy. This area may then be pasted into another application or repositioned on the graphics window for printing.

Paste

The **Paste** command is used to paste a picture or text that has been copied or cut to the clipboard. The cursor can be used to select the location within text for a **Paste** . Graphic objects are pasted into the upper corner of the current window or highlighted marquee area. **Paste** can also be done using the **⌘-V** command-key.

Select All

This menu selection can be used in graphics or text windows to select all plotted items or all displayed text prior to processing them with commands such as **Copy** or **Search For**. This can be selected with the **⌘-A** command-key.

Tabs-to-Spaces

The **Tabs-to-Spaces** command replaces all of the Tabs in the active text window with spaces. The original spacing is kept the same, except that there are no longer Tabs in the text.

Original Size

This command will restore a picture to its original size if it has been manually resized by the user (see Section 5.5). The ability of OATS to restore the size of a picture is limited to the location of the upper left corner. If a resize has been done by moving the upper or left side, **Original Size** may do nothing.

Combine

The **Combine** function is not shown in Figure 5-9, because it appears in place of the **Original Size** command after the user has drawn at least 2 layers in the graphics window and has executed the **Select All** command. It is used to group several layers of pictures into a single picture, usually prior to a **Save** command.

Search For...

This command applies to text windows. It brings up the dialog seen in Figure 5-10, which allows the user to search for and replace character strings. Since the OATS text windows are used for text output and not as editors, the *Find* aspect is of most importance. It can be used for example to quickly locate the first occurrence of an output record in a lengthy tabular display with a particular time tag. This can be initiated with the **⌘-F** command-key.

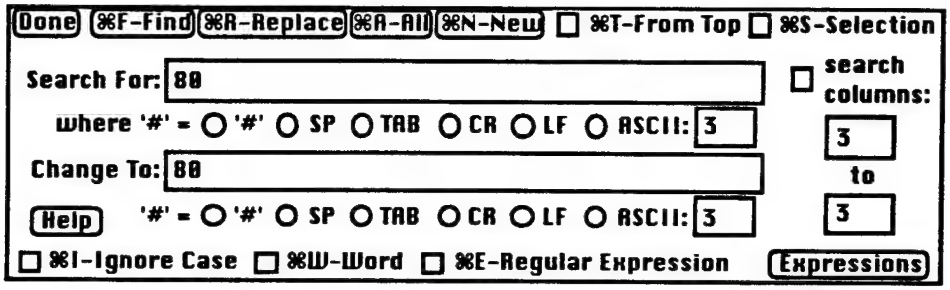

Figure 5-10. Search Interface Provided by FACEIT

Bring to Front

The **Bring to Front** command is used to bring the selected layer of graphics to the top layer. This command only becomes activated (non-grayed) in the menu if a layer other than the top layer has been selected. This can also be initiated with the **⌘-F** command-key.

Next Case

This command is used after the **Search For** command has initialized a character field that is being sought. It highlights the next occurrence of the string input in the **Search For** dialog box.

Send to Back

This command allows the user to send the top layer of the graphics window to the bottom layer. A new top layer can be activated by clicking on one of the objects in the layer of interest.

⌘ Return

This command is only active for editor-type windows, which are supplied by FACEIT. These windows act as independent entities and can be used to enter and save data in a fashion not connected to an executing OATS process. When used for the purpose of communicating data into OATS, an editor-type window requires a command that signals to OATS that data is being sent from the editor. The **⌘ Return** command functions as the send command (see Section 6.3.2 for an example of the use of this command).

5.4 WINDOW MENU

OATS makes use of four work windows, which are described in Section 3.1. The **Window** menu provides the controls which allow the user to manipulate and define these windows as needed for his applications. The available options include such choices as hide or display windows, font sizes, and dimensions of graphics displays. As with the **Edit** menu, the menu selections vary depending on whether the Graphics Window or an editor-type window is the active window. The menu for the Tabular Window and Preview Ephemeris Window (editor-types) is shown in Figure 5-11. The equivalent menu for the Graphics Window is shown in Figure 5-12. Again, the different options with the same command-keys will appear in the same menu position depending on the active window. The **Window** menu has one variation that will be discussed in Section 5.5.

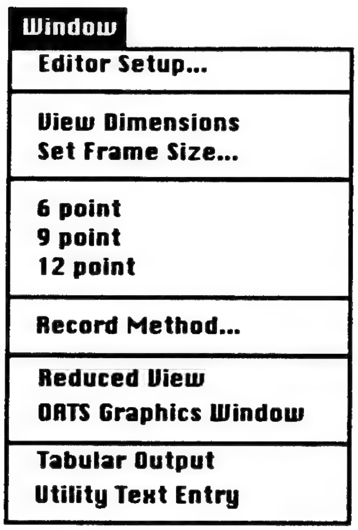

Figure 5-11. **Window** Menu for OATS in Tabular Mode

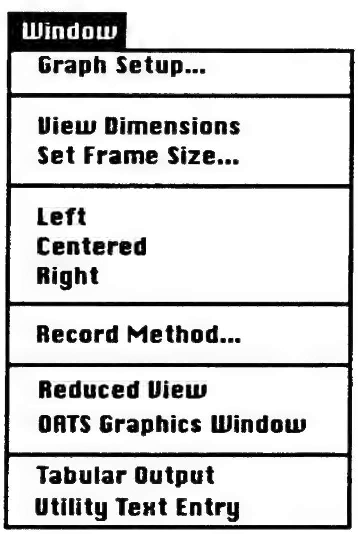

Figure 5-12. **Window** Menu for OATS in Graphics Mode

Editor Setup

This command brings up the dialog shown in Figure 5-13, and allows the user to define selected characteristics of whichever editor window is currently active. As OATS uses the editor windows primarily for text viewing rather than as formal editors, this dialog is of modest importance; however, it does allow the user to specify the following window characteristics:

- The size of the space inserted by pressing the **TAB** key
- Activation or deactivation of automatic indenting of entered text.
- Options on how the editor interprets the **ENTER** key.
- Options on file handling. The *Help* button produces a dialog with additional information on what these options mean.
- Activation or deactivation of the option to show the cursor position and selection size. When activated, the position and size of a text selection are temporarily shown in the window title bar when the mouse button is pressed.

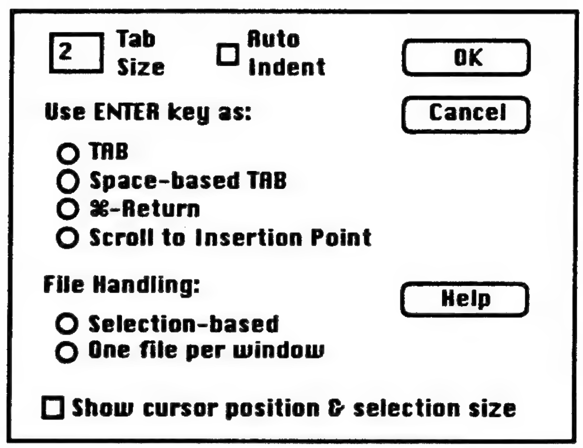

Figure 5-13. Editor Window Set-Up Dialog

The **Editor Setup** is probably most important in cases where the user wishes to make manual annotations to output listings which already exist in the Tabular Window prior to saving them to an output file.

Graph Setup

This command brings up the dialog shown in Figure 5-14, and allows the user to define the Graphics Window. This setup dialog is one of the first ones that a user should become familiar with when starting work with OATS. It should be used to set the Graphics Window to a size appropriate to his needs, to his monitor, and to the power of his computer. The user will find that a large screen is easier to work with and provides a better view, but it also implies more pixels to process and plot and a consequently slower response time.

The FACEIT environment provides the capability to make plots onto a grid of n-by-m pages, as reflected by the *Pages* fields in this dialog. Each page will be of uniform *width* and *height*, as set by the user. The *Screen Size* button can be used to quickly set the page *Size* to the maximums allowed by the monitor; however, it should be noted that a non-square monitor may not necessarily produce the most meaningful plots. The typical user will find that a 1-by-1 page size works best for most OATS processes. Larger page groupings are seldom necessary, and their use is discouraged. Multi-page displays can also confuse new users regarding where a plot is being generated; however, the *Pages* settings are available if there is a need to plot multiple displays side-by-side and in the same saved picture. The Reduced View window shows the full-available plot area, and is used to keep track of where the visible Graphics Window is currently viewing. The **TAB** key and **Shift-TAB** keys move the visible Graphics Window from page to page. Once the Figure 5-14 Setup Dialog has been exited, the drawing area can be opened to its full size by clicking and dragging the box located at the bottom right of the Graphics Window.

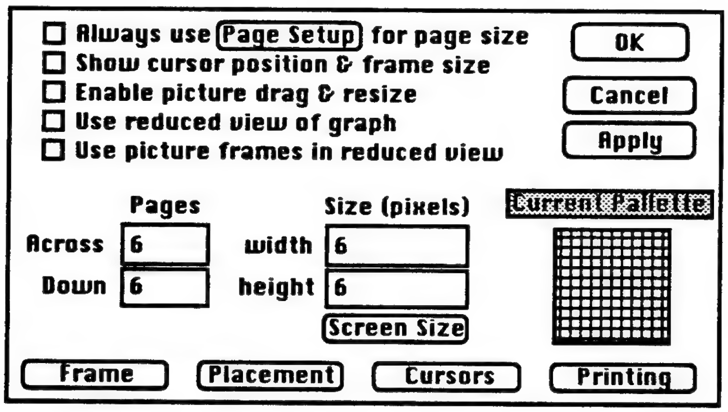

Figure 5-14. Graphics Window Set-Up Dialog

The five checkboxes at the top of the dialog provide options regarding the use of the graphics Window. The *Page Setup* button produces the same setup dialog as the **Page Setup** menu under **File** (see section 5.2), and can be used as an alternative to setting the Window size using the *Size* settings. If the second checkbox is activated, the cursor position and frame size are temporarily displayed in the window title bar whenever the mouse is pressed. The ability to drag and resize pictures can be enabled/disabled, as can the use of the Reduced View Window. The last option specifies that pictures in the Reduced View Window will be shown as rectangular-area blocks, rather than as individual objects. The area shown as a checkerboard in Figure 5-14 will display the current available colors (palette) for use by OATS. The default palette is clut 600 (color look-up table), which contains a diverse spectrum of 256 colors. By clicking the *Current Palette* button, a pop-up list of other palettes is shown from which the user may select a different

palette. This list should include a black-and-white palette as well as a reduced set of colors. Clicking the *OK* or *Apply* buttons will establish the new selection as the current palette. The *Frame*, *Placement*, *Cursors*, and *Printing* buttons each produce a dialog from FACEIT that provides mini-tutorials for the user on these subjects as related to the OATS graphic window. They are useful and should be studied by a first-time user.

View Dimensions

This command brings up the informational dialog shown in Figure 5-15. Regardless of which window is currently active, it provides a summary of the settings in place for the Graphics Window. Horizontal and vertical sizes in pixels and in inches are shown. The screen resolution in pixels/inch is provided, even though this is constant at 72 pixels/inch for most Macintosh computers. The center of the dialog shows a small pseudo-window with the *Top*, *Left*, *Bottom*, and *Right* values of the frame boundaries. These dimensions uniquely define the area currently in use as the drawing frame (area in the marquee).

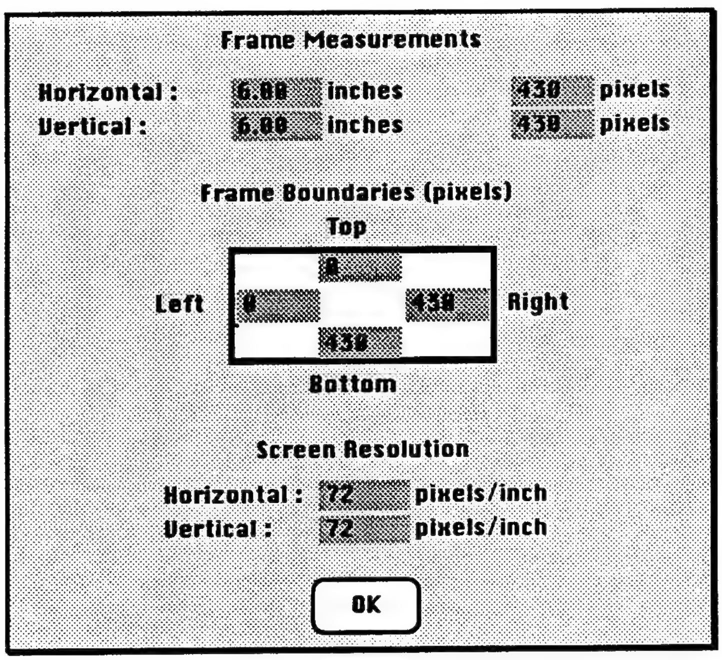

Figure 5-15. Graphics Window Summary Display

Set Frame Size...

The dialog shown in Figure 5-16 is displayed after this menu selection. This dialog presents an alternative to selecting the drawing frame area by using the click-and-drag method (See Section 4.5), which requires the user to "eyeball" the appropriate size for the frame settings. **Set Frame**

Size allows the user to select the exact pixel settings for the *Top*, *Left*, *Bottom*, and *Right* sides of the frame. These settings will work in a multi-page environment. The *View* button will provide an update of the *Length* and *Width* according to your current settings. Upon an *OK* exit from this dialog, the marquee will be presented as per your settings.

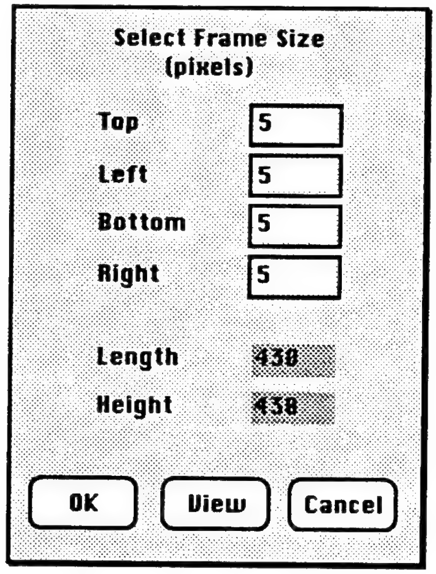

Figure 5-16. Dialog for Specification of Frame Size

6 point // 9 point // 12 point

Each of the editor-type windows can be viewed as a 6, 9, or 12 point font. When either of these windows is active, these font size choices are available and can be selected by highlighting the desired value with the mouse. The current value is shown with a check in front of it in the menu. Each window can have its own setting, and settings are maintained between executions of OATS according to the last **Save Settings** command (see Section 5.2).

Left // Centered // Right

These options are the choices for justification of text inserted into the Graphics Window. Text insertion is described in Section 5.5. The **Left**, **Centered**, and **Right** options become active only after text insertion has been initiated. The current setting is shown by a check in front of it in the menu. Once set and saved with the **Save Settings** command (see Section 5.2), the justification setting will be maintained between initiations of OATS.

Record Method...

The dialog shown in Figure 5-17 is displayed and allows the user to select the manner in which plotted data is composed and recorded. An OATS *Picture* is composed of a collection of QuickDraw (Reference 2) routines that produce basic geometrical shapes like lines, ovals, and rectangles. A *Bitmap* is composed of a grid of pixels with assigned values of black/white or of

color. Although Bitmap recording is most often the method of choice for OATS applications, the specific choice depends on the user's intended use of the plots. *Picture* drawings can be edited by MacDraw-like graphics editors; however, *Bitmap* plots are faster and require less memory for almost all normal OATS applications. OATS plots can be composed of combinations of drawing layers done with a mixture of *Picture* and *Bitmap* settings; however, there is seldom any motivation to do so.

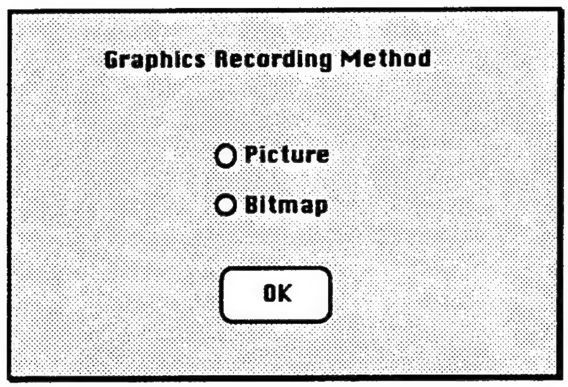

Figure 5-17. Dialog for Selection of Data Recording Method

Reduced View
OATS Graphics Window
Tabular Output
Utility Text Entry

OATS and FACEIT provide these menu options to allow the user to immediately activate (open and/or bring to the front) the desired window. Note that they are grouped according to whether the windows are graphics-oriented (Reduced View and OATS Graphics Window) or are editor-type windows (Tabular Output and Utility Text Entry).

5.5 <u>NON-MENU PROCEDURES AND COMMANDS</u>

Several environment-controlling procedures and commands are available that are not specifically called out in the menus. Some information is available using the bottom buttons shown in Figure 5-14; however, they are important enough to be reviewed below.

- Closing Windows - All windows used in OATS have a close button in the upper left hand corner which can be clicked to close that window. This applies for all phases of execution, except for the Utility Text Entry window used in Preview Ephemeris File mode. Its parameters can be set using the **Window** commands (see Section 5.4); however, its opening and closing are controlled during program execution by selected key strokes (See Section 9.2).

- Text in Graphics Window - This feature is useful for labeling graphics with, for example, titles, contour value settings, or coordinate values. To insert text into the Graphics Window (does not work for Reduced View Window), define a text area by pressing the Apple key and then click-dragging out to the limits of the desired area. Then press the **ENTER** key and a text cursor will appear. At this point the **Left**, **Centered**, and **Right** justification options become active, with the active value shown by a check in front of it in the menu. The **Reduced View** menu option is also temporarily replaced by a **Font,Size,Style** option. If selected, a dialog like that shown in Figure 3-6 will appear and allow the user to set the color, size, and characteristics of the text in the graphics window. These characteristics are not preserved between different executions of OATS. When finished typing, press the **ENTER** key again and OATS will return to the normal graphics mode. More help on this subject can be found in the **Graph Setup** dialog by clicking the *Frame* button.
- Deselecting Plots - A simple click in the Graphics Window outside the marquee will deselect all plotted items and set the marquee equal to the entire window.
- Square Marquees - When manually defining a marquee area, it is possible to force the area to be square by having the **CAPS LOCK** key pressed.
- Resizing Plots - To manually resize a plot or one drawing on a plot, move the cursor to the edge of the drawing and the cursor will turn into an arrow. Click-drag the edge of the drawing to the desired size This may be accomplished by extending one edge at a time, or by click-dragging on a corner of the drawing area to expand height and width simultaneously. Alternatively, a drawing can be resized by placing the mouse at the extreme point where the marquee is to be expanded to, holding the **SHIFT** key, and clicking the mouse.

SECTION 6 - PROPAGATE MENU

The OATS program combines orbit propagation models with numerical and graphical coverage analysis algorithms. The design philosophy of OATS has been to separate the orbit models from the analysis processes. The primary reason for selecting this architecture is so that an arbitrary number of different orbit propagation models can be added to the program without affecting any of the analysis code; however, this architecture also makes it possible to perform analysis on an imported ephemeris generated by an external program that might use a propagator not available through OATS. Thus, as previously noted, the user must always have satellite ephemerides available before proceeding with any of the OATS coverage analysis functions. Although it is expected that a typical user will employ the OATS **Propagate** menu to generate ephemerides prior to performing analysis, imported ephemeris files can be used if they follow a prescribed format (see Section 10.2). The only difference apparent to the user between internally generated ephemeris files and imported ones is that processing will be slightly faster for the internally generated files.

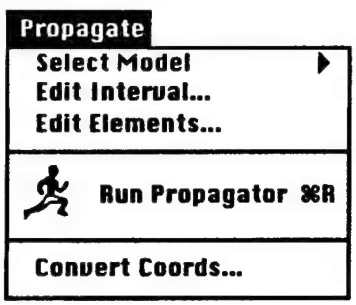

Figure 6-1. **Propagate** Menu

The **Propagate** menu is shown in Figure 6-1. It is an OATS analysis tool used to generate ephemeris files using one of a variety of orbit propagation models. The **Select Model**, **Edit Interval**, and **Edit Elements** menu selections are employed to set-up a computer run that will generate an ephemeris file. Their functions include access and display of orbital element sets. Once set-up is completed, **Run Propagator** is used to create the ephemeris file that can be used for graphical or numerical coverage analysis. This menu tree also provides a secondary capability via the **Convert Coords** option to transform from one type of orbital element set to another.

6.1 ORBIT PROPAGATION MODELS

Satellite ephemerides can be computed by any one of four orbit propagators provided with OATS version 3.0. The abbreviations for each of these models is the same as those used in the OATS menu system. The format for the orbital elements for each propagator is provided in Section 10.1.

- **PPT2** - This propagator uses a full Brouwer-Lyddane analytic model for propagation and requires the input of a One Line Element Set (OLES). Three different OLES formats are available, including:

  PME

  Charlie

  Z (also designated Zulu)

- **RUK12** - This is a fourth order Runge-Kutta numerical integration with a WGS84 geopotential of order and degree 12. The input for this model is an osculating Cartesian state vector and an epoch for the state vector. This model requires a small integration step size to obtain accurate results (typical values range from 1 to 10 seconds). This step size is rather small for plotting and coverage analysis and tends to yield very large ephemeris files to store the data. Because of this, the user specifies the integration step size for the propagation as well as an output interval for the ephemeris data.
- **J2** - The J2 propagator uses a first order analytic theory with earth oblateness effects. The input elements are mean Keplerian orbital elements and an epoch for these elements.
- **SGP4** - This is used to propagate Two Line Element Sets (TLES) generated by USSPACECOM (formerly NORAD). The model is used for near-Earth satellites, defined by USSPACECOM as having periods under 225 minutes. The SGP4 model (Reference 5) was developed by Ken Cranford in 1970. It is a simplification of the extensive Lane and Cranford analytical theory, which uses Brouwer's solution for its gravitational model and a power density function for its atmospheric model.

6.2 PROPAGATION COORDINATE SYSTEMS

Two coordinate systems are referred to through the remainder of this section. They are Earth Centered Inertial (ECI), and Earth Centered Fixed (ECF). The fundamental plane of the ECI system is the mean Celestial Equator. The x-axis lies in the direction of the Vernal Equinox and the z-axis points toward the North Celestial Pole. The ECF system is a non-inertial, rotating system which is fixed to the earth. The fundamental plane of the ECF system coincides with that of the ECI system. The x-axis is rotated about the Celestial Pole through the Greenwich hour angle. The effects of precession and nutation of the Earth pole are ignored. All of the analysis and plotting functions in OATS to which satellite ephemerides are input require the coordinate frame to be ECF.

6.3 HOW TO GENERATE AN EPHEMERIS FILE

6.3.1 PROPAGATOR MODEL SELECTION

To set up an ephemeris generation run, choose the **Select Model** option from the menu shown in Figure 6-1. This will produce the sub-menu shown in Figure 6-2, which allows the user to select one of the four

orbit propagation models described in Section 6.1. Choice of PPT2, RK12, J2 , or SGP4 will all directly bring up individual dialogs that allow the user to enter specific orbital element data, with the exception of the PPT2 option which has an intermediate step. Choice of PPT2 will bring up the simple dialog shown in Figure 6-3, which is used to distinguish between the three OLES formats. *Cancel* will return the user to the main menu, but selection of *OK* will pass the user on to the next dialog as determined by the user's selection for the PME, *Charlie*, or Z radio buttons.

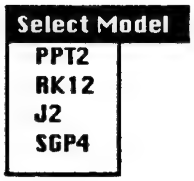

Figure 6-2. **Select Model** Menu

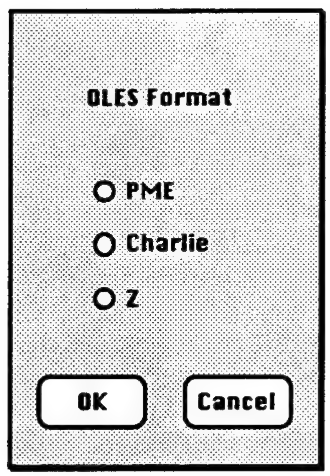

Figure 6-3. Dialog for Selection of Type of One Line Element Set Orbital Elements

6.3.2 ORBITAL ELEMENT DATA ENTRY

Orbital elements are entered via one of the dialogs shown in Figure 6-4 through Figure 6-9. These dialogs are used all places throughout OATS where it is necessary to view the orbital elements. In their native format, some of the orbital element formats are condensed (see Section 10.1) and it is awkward to visually interpret the component parts. Through this set of dialogs, OATS provides the service of a user friendly display of the orbital elements for each of the propagation models. Note that OATS maintains a single storage location for each of the four types of orbit element propagators. Hence, if at first a set of J2 elements is being manipulated and the user changes to RUK12 for a while and then returns to J2 , the J2 data will be maintained. These six dialogs are very similar in many respects, and are discussed as a group. Explanation of the orbital element components is provided in Appendix C.

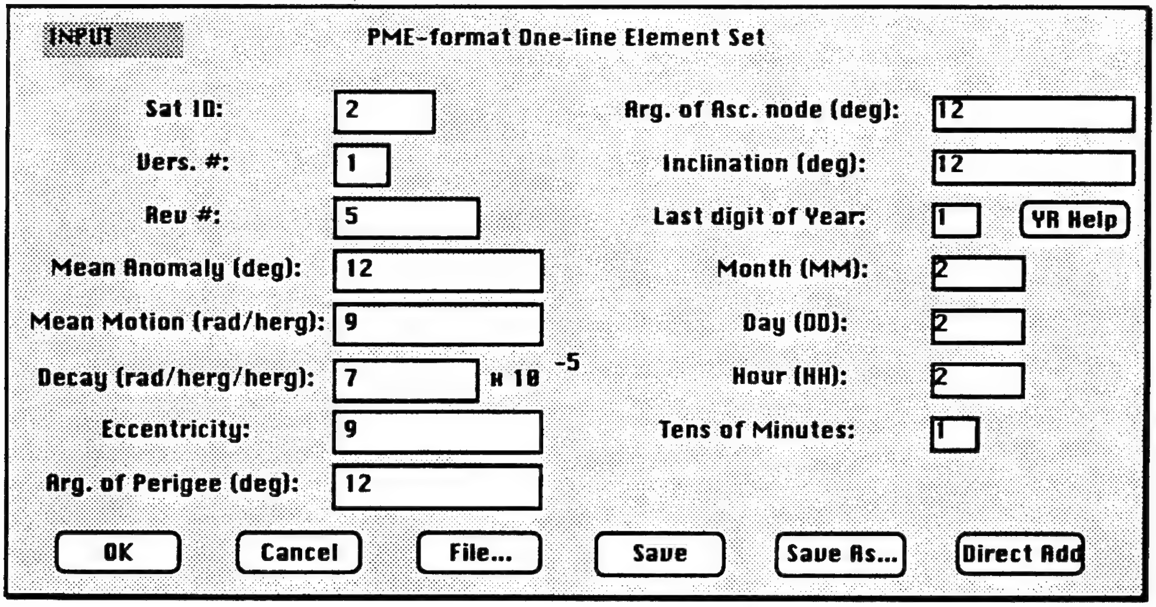

Figure 6-4. Dialog of Orbital Elements for PME Format One Line Element Set

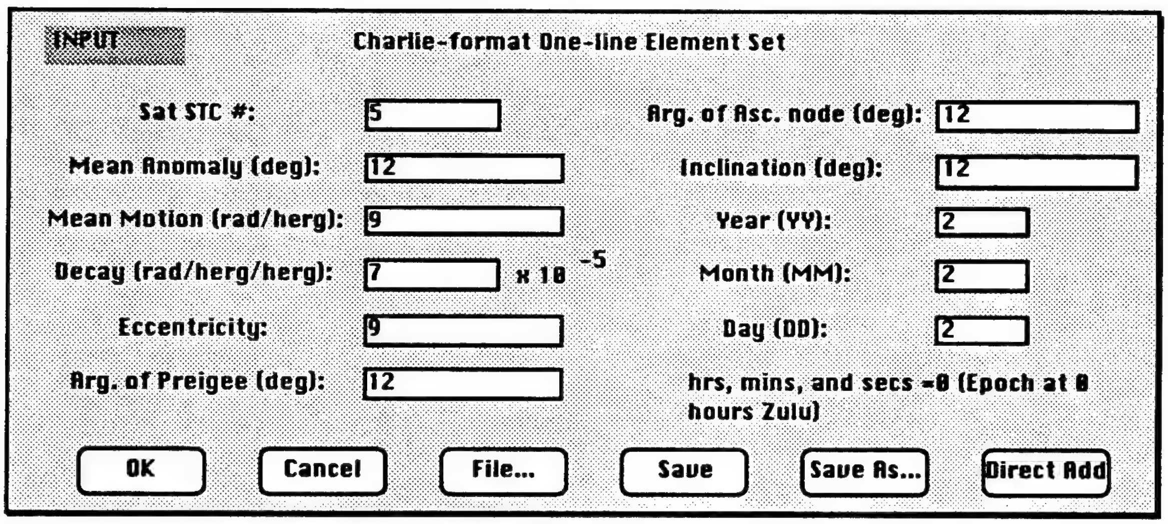

Figure 6-5. Dialog of Orbital Elements for Charlie-Format One Line Element Set

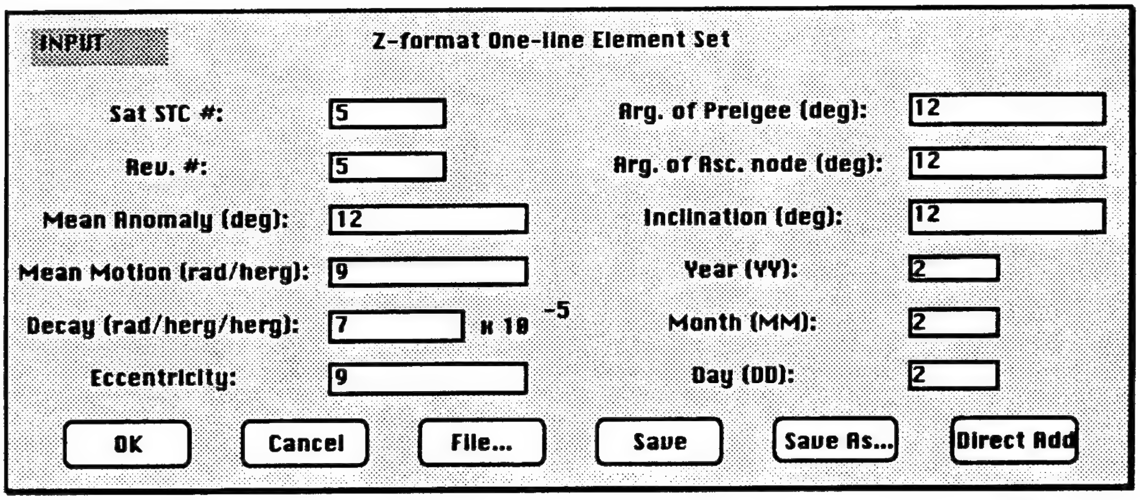

Figure 6-6. Dialog of Orbital Elements for Z-Format One Line Element Set

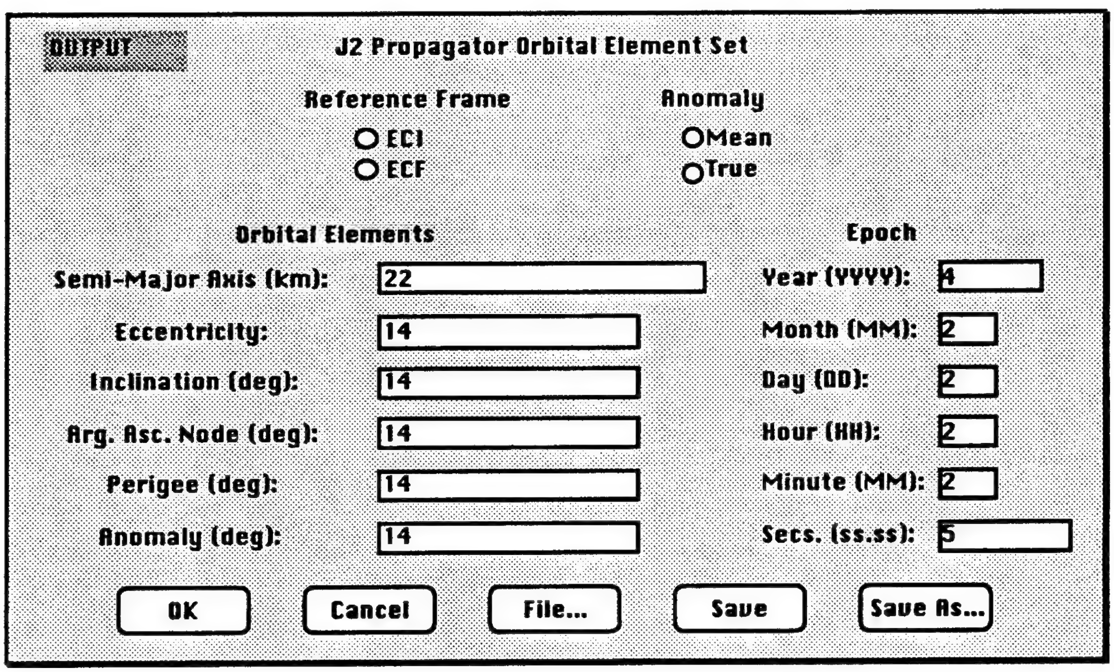

Figure 6-7. Dialog of Orbital Elements for J2 Propagator

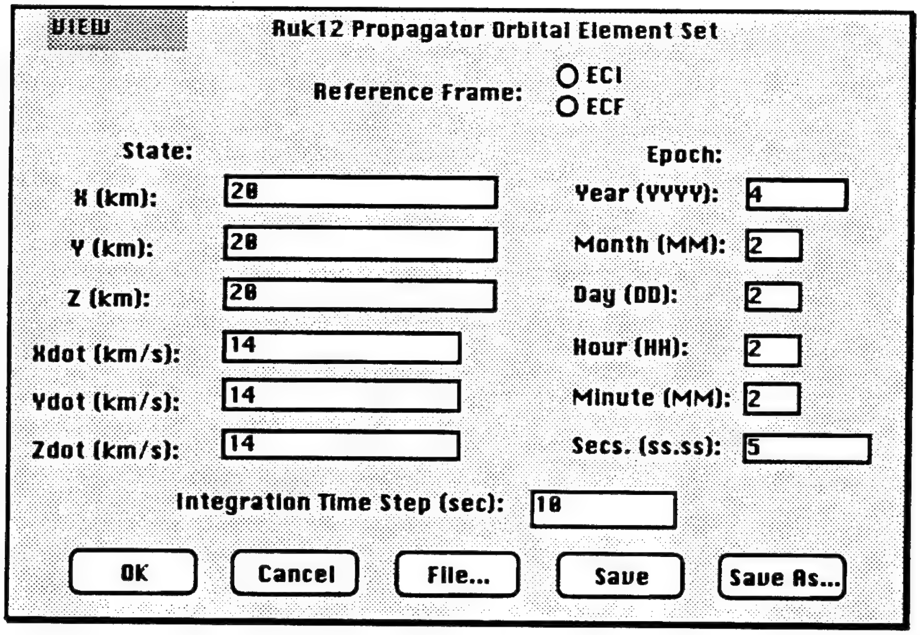

Figure 6-8. Dialog of Orbital Elements for Runge-Kutta Propagator

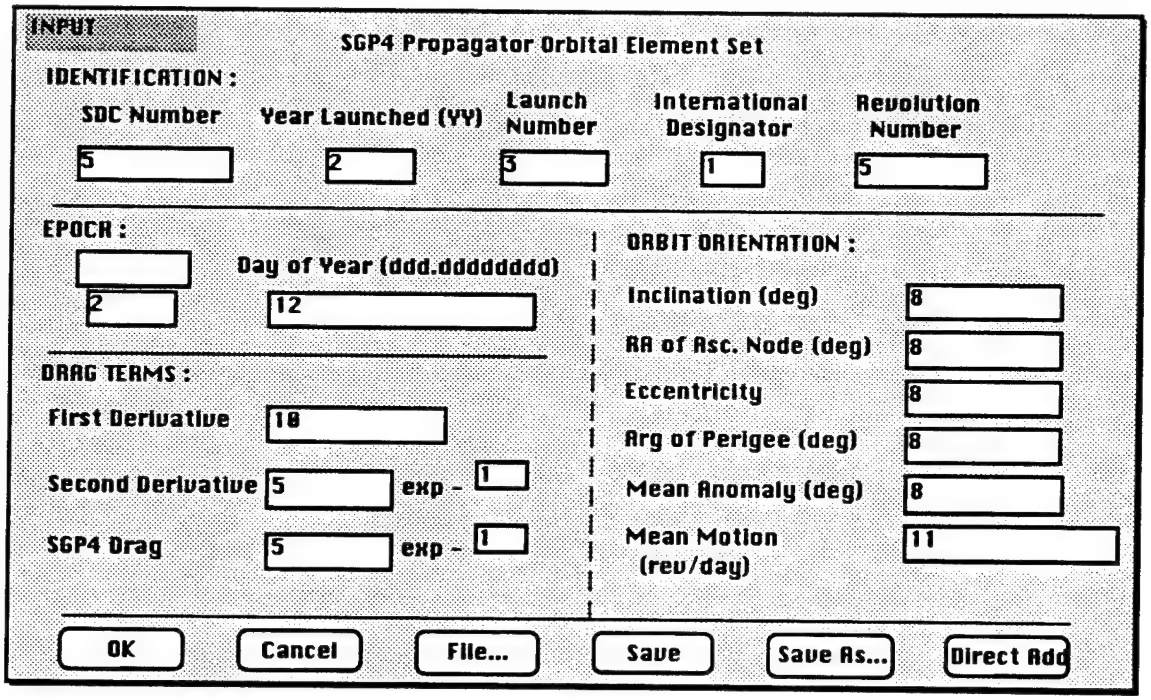

Figure 6-9. Dialog of Orbital Elements for SGP4 Two Line Element Set

The various input fields for all six dialogs are all individually labeled, and should be generally self-evident if the user understands the discussion presented in Appendix C. All input fields are labeled with appropriate units, if any, and the user is advised to strictly adhere to them. In addition to their input fields, the J2 and RUK12 input dialogs also have a set of radio buttons to choose whether the reference frame is ECI or ECF. The J2 dialog has an additional set of radio buttons to choose if mean or true anomaly is employed in the orbital elements. Note that the orbit epoch *Year* is entered as a 4-digit integer for the J2 and RUK12 cases, as a 2-digit year spanning the range from 1951 through 2050 for the SGP4, PPT2-Charlie, and PPT2-Z cases, and a 1-digit year for the PPT2-PME case. This very narrow range for the PPT2-PME case has necessitated the addition of a special button in the dialog shown in Figure 6-4. The *YR Help* button will bring up the dialog shown in Figure 6-10 that allows the user to unambiguously select any 4-digit year as the start year for the 10-year span of validity. The RUK12 orbit propagator also carries a place to input the *Integration Time Step*, which is the interval used by the orbit propagator to perform computations. This interval should not be confused with the ephemeris interval (see Section 6.3.3) which is the time step used to output ephemeris computations. The *Integration Time Step* should be smaller than or equal to the ephemeris interval.

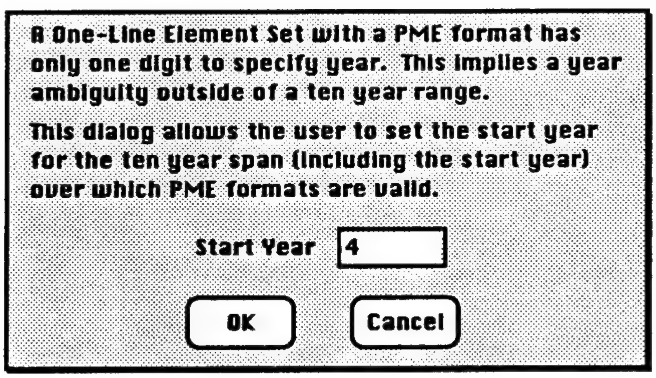

Figure 6-10. Dialog for Specification of Year Interval for PME-Format One Line Element Set

Each of the orbit element dialogs in Figures 6-4 through 6-9 also provides five identical main option buttons. The *File* button brings up a standard Macintosh interface dialog which allows the user to locate an existing input file of orbital elements in any directory. *Cancel* or *OK* from this standard interface dialog will both return the user to the orbital elements dialog. OATS performs only basic file I/O checks at this point, returning an alert if the file cannot be opened or if a read error occurs. *OK* from the standard interface dialog will immediately read the file of orbital elements and display the retrieved values, even if they are not valid.

The *Save As* button in the orbit element dialogs brings up a standard Macintosh interface dialog which allows the user to specify the name for an existing output file of orbital elements in any directory. *Save*

will overwrite a previously saved file of orbital elements without comment. If a previous save has not occurred, *Save* behaves like the *Save As* option.

The *Cancel* button in Figures 6-4 through 6-9 returns the user to the main menu with no changes made to the orbital elements seen when the dialog was opened. *OK* will perform checks on the data as entered before exiting the dialog and issue an alert if a problem is detected; however, the checks are limited. **The user is cautioned that he is ultimately responsible for the validity of entered data.**

The OLES and TLES orbital element sets appear in a condensed form in their native format (see Section 10.1). The dialogs for these orbital element sets, Figures 6-4 to 6-6 and Figure 6-9, have an additional button called *Direct Add*. Although it is faster to enter orbital elements via a file prepared prior to running OATS or by entering them directly into the separate fields in the dialogs, this is not always the most convenient option. The *Direct Add* feature is available for those cases where the user wishes to enter an OLES or TLES directly and verbatim into OATS. Punching this button on an OLES dialog will bring up the Utility Text Entry window and print a template line for the element set. The user should type in the required data below the template, make certain that the cursor is located at the end of the entered line of data, and enter a **⌘ Return**. OATS will read the entered line, return to the dialog, and display the data appropriately in the separate dialog fields. If an entry error is made prior to the **⌘ Return** command, the user may make corrections by moving the cursor and changing fields as needed because the Utility Text Entry window is configured as an editor. If an undetected error is entered, OATS will issue an alert and return to the dialog. To abort the process, just enter **⌘ Return** and ignore the resulting alert. For a TLES, a similar procedure is followed, except that two lines of user input will be required.

Because the orbital elements dialogs are used in multiple places, a flag field appears in the upper left corner of each dialog. This flag field has the values:

- INPUT - orbital elements are being used as program input
- OUTPUT - orbital elements have been produced as computed values
- VIEW - orbital elements are presented for inspection only and cannot be altered

For generating an orbit ephemeris, the flag field should read INPUT.

6.3.3 INTERVAL SELECTION

When the user passes through the **Select Model** menu option and subsequently exits any of the orbit element entry dialogs with an *OK*, the *Set Ephemeris Interval* dialog shown in Figure 6-11 is automatically displayed. The primary function of this dialog is to set the interval of the generated ephemeris file. The *Specify by* radio buttons permit choosing the interval via inputs of *Start Time* and *Stop Time* or by *Start*

Time and a user selected number of revolutions. As shown above, all orbit elements have an epoch date, at which time the elements are valid. This date is entered in the preceding dialog, and is displayed as the default *Start Time* ; however, it can be manually changed. The *Step Size* in seconds is the interval between computed ephemeris records.

If the interval is specified by the number of revolutions rather than being manually entered, the user may verify that the interval is acceptable by punching the *SHOW Conversion* button. The *Stop Time* will be computed using Kepler's equation and displayed. It is not required to make this check--the user may exit with an *OK* and the *Stop Time* will be internally computed. Note that if a new number of revolutions is selected after computing a *Stop Time*, the computed time is not used. Negative values of revolutions are unacceptable, as is a manually entered *Stop Time* that implies an orbit propagated backwards in time. Exiting the dialog in Figure 6-11 with either the *OK* or the *Cancel* will return the user to the main menu.

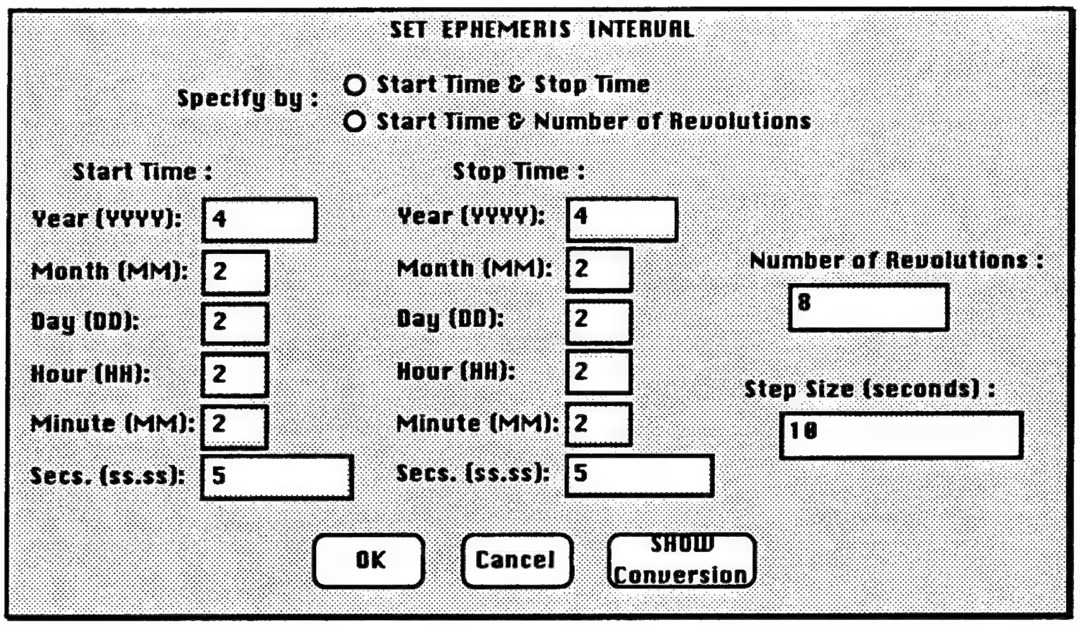

Figure 6-11. Dialog Used to Set Ephemeris Interval

6.3.4 SET UP CORRECTIONS

Before initiating the ephemeris file generation, the user may modify the orbital elements and/or the ephemeris interval by using the **Edit Interval** and **Edit Elements** menu options from Figure 6-1. Editing the orbital elements by way of the **Edit Elements** menu will not automatically bring up the interval dialog. If the user wishes to change the model for the orbit propagator, it is necessary to start over with **Select Model**. Similarly, these two menu options are not valid choices if a propagator model has not been selected. An alert will be issued.

6.3.5 GENERATING THE EPHEMERIS FILE

After all data have been entered, the ephemeris file generation is initiated with the **Run Propagator** command from the **Propagate** menu in Figure 6-1. Alternatively, the **⌘-R** command key may be used. After initiation, the user will be presented with the Macintosh standard file interface so that a name and location for the ephemeris file can be selected. Exiting this dialog with an *OK* will create an ephemeris file. If the user has elected to have a progress display (see **System Params** under Section 5.1), a graphic will be presented showing the file name, a tabular value of percentage of file completed, and a fill-bar graphic showing progress toward completion. This graphic can be valuable in cases where very large files have been selected or when a poor selection of generation parameters results in a file that is undesirably large. If the user suspects there is a problem, the file generation process can be stopped by clicking the mouse button. An alert will be issued, processing will stop, and any portion of the generated ephemeris file will be deleted. When a new ephemeris file is generated by OATS using the procedures described here, the file is automatically added to the list of active ephemeris files. The significance of this is explained in Section 9.1.

6.4 COORDINATE CONVERSIONS

A limited set of orbit element coordinate conversions is made available through OATS. The possible conversions can be seen graphically in Figure 6-12, the dialog that is presented to the user after selecting the **Convert Coords** option from the **Propagate** menu. The user should note that no orbit element coordinate conversion is going to be exact. For proper and precise propagation of an orbit, the orbit element set must be matched to the propagator model for which the elements were computed. However, these coordinate conversions do serve several useful purposes:

- They will provide a more intuitive look at an orbit specified by an OLES or TLES by presenting it in a Cartesian or Keplerian format.
- They make comparison of two differently specified orbits possible by providing a common format for orbit element display, even if the computed values are only very close approximations.
- They provide a basis for transforming an orbit element set so it can be used by another piece of software that cannot handle some of the orbit propagation models that OATS has available.

An orbit element coordinate conversion is performed by selecting one of the mutually exclusive set of *FROM* elements and one of the mutually exclusive sets of *TO* elements. *Cancel* will return the user to the main menu, and *OK* will bring up one of the orbit element dialogs in Figures 6-4 through 6-9. The flag field will be set to INPUT to show that the user is expected to input the orbital element set that will act as

the source data to be converted. Data entry into these dialogs for coordinate conversions is handled just as was described in Section 6.3.2 for data entry to generate an ephemeris file. For OLES data, the dialog seen in Figure 6-3 again is used as an intermediate step.

When the INPUT coordinates are set, and an OK is clicked, the conversion will be performed as specified in the opening dialog (Figure 6-12) and the output will appear in a dialog like that shown in Figures 6-7 or 6-8. The flag field will show OUTPUT to indicate that the displayed data is a computed product. Orbit elements can be saved to an external file, which is a useful feature for performing comparisons.

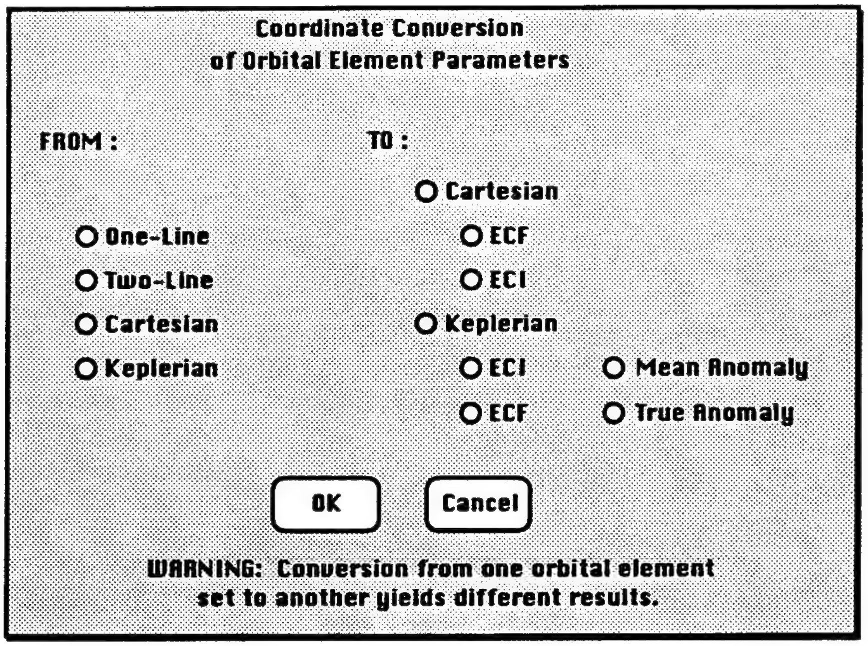

Figure 6-12. Dialog for Selection of Type of Orbital Element Coordinate Conversion

SECTION 7 - PLOT MENU

All of the OATS plot functions are defined and initiated through the **Plot** menu shown in Figure 7-1. Because graphical displays of satellite coverage and coverage related phenomena are the primary thrust for the development of OATS, this menu is quite important and has many options. It is organized into two primary groups of commands. The first grouping is a set of ten commands that allow the user to directly plot satellite coverage or to plot structures like target positions or a satellite track that are related to coverage. These ten commands appear numbered in the **Plot** menu, and the numbering scheme is maintained wherever there is an OATS function related to plotting. Note that there is an intentional symmetry in the plotting menus and their associated commands. This leads to many similarities in the descriptions of the sub-menus and associated dialogs; however, the somewhat repetitious nature is required for those users that employ the manual to look up single commands rather than for cover-to-cover reading. The second grouping of selections at the bottom of the menu is a set of miscellaneous plotting commands that enhance the display or usefulness of the first 10 basic plot functions. The **Map** menu and its options are especially important to the operation of OATS. The **Map** menu is handled as a section unto itself.

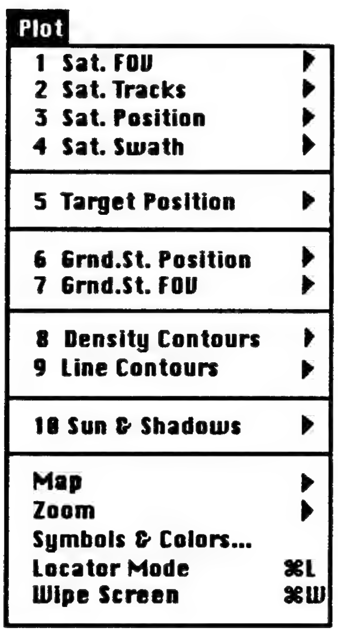

Figure 7-1. **Plot** Menu

All plot activity initiated from the **Plot** menu will manifest itself in some way in the OATS Graphics Window. The user should note that it is not necessary for the Graphics Window to be visible or active for plotting to occur; however, it is generally advisable to have the Graphics Window active so that the user can see what is drawn as it appears on screen.

7.1 SHARED FEATURES OF PLOT-STRUCTURE COMMANDS

The ten structure commands in the **Plot** menu share certain common features. For the sake of brevity, the common features are presented in this section and only briefly noted when the structure commands are presented individually.

Figure 7-2 shows the menu selections available for **Satellite Field-of-View**. Although it is preferred to show full titles for each of the structure commands, space limitations dictate that some of the menu options are abbreviated. The convention will be to use the unabbreviated commands when presenting the menu selections.

Figure 7-2. **Satellite Field-of-View** Menu

Each of the ten structure commands begins with an **Options** selection that presents a dialog that allows the user to set parameters that define the graphic to be plotted. Each structure menu finishes with a **Plot** selection that initiates the defined plot. The **Plot** commands can also be initiated with a **⌘-n** command-key, where "n" is one of the ten numerical characters from "1" through "0" (the zero is tenth) corresponding to the sequence of the plot-structure command. In most cases, a single new layer will be added to the existing figures in the Graphics Window; however, there are some types of plots which involve labeling where all previous layers must be combined to successfully execute the desired structure plot.

Depending upon function, the structure commands will also have **Color**, **Line Color**, or **Shading Color** commands available. As examples, consider that the target position requires a **Color** because it is plotting a target icon at a user-defined geographic position. Satellite track plots use **Line Color** because a single-line path for the satellite is plotted. Ground station FOV requires both **Line Color** and **Shading Color** because the outline of the FOV and/or the shaded area covered by the FOV can be plotted. Any of these color-related selections will bring up the Color Selection utility dialog discussed in Section 3.5 and shown in Figure 3-5. This technique for selecting colors also works well in black-and-white computer environments where shading is displayed using a gray pattern. A default is provided for every color, and all color settings are maintained between OATS executions.

7.2 PLOT-STRUCTURE COMMAND MENUS

7.2.1 SATELLITE FIELD-OF-VIEW

The **Satellite Field-of-View** menu was shown in Figure 7-2, and all its menu options are explained in Section 7.1. This plot command is used to plot the FOV seen by a satellite antenna that is nadir-pointing and cone shaped. The dialog that appears from the **Options** command appears in Figure 7-3. This dialog is not available to the user unless at least one ephemeris file has been opened (see Section 9.1). A list of files in the active *Ephemeris File List* appears in the scroll list to the left of the dialog. The satellite FOV is plotted from whichever of these files is active. The first open file is the default selection when this dialog is initially accessed, but a different ephemeris can be selected by double clicking the mouse on the name of the new file in the list. Once selected, the identity of this active file is distributed to most of the **Plot** dialogs. To eliminate uncertainty, the name of the active file is displayed in the *Active File* area below the list. The *Time* at which the FOV will be plotted is displayed in the *Year, Month, Day, Hour, Minute,* and *Secs* fields to the upper right of the dialog. The time is defaulted to the beginning of the ephemeris file, but can be reset by the user to any time during the interval covered by the file. As an aid in selecting the *Time,* the *Time Span* is displayed and shows the limits covered by the current active file. The *Time* displayed in this dialog is linked to the time shown in the **Satellite Position** and **Sun & Shadows** menu items

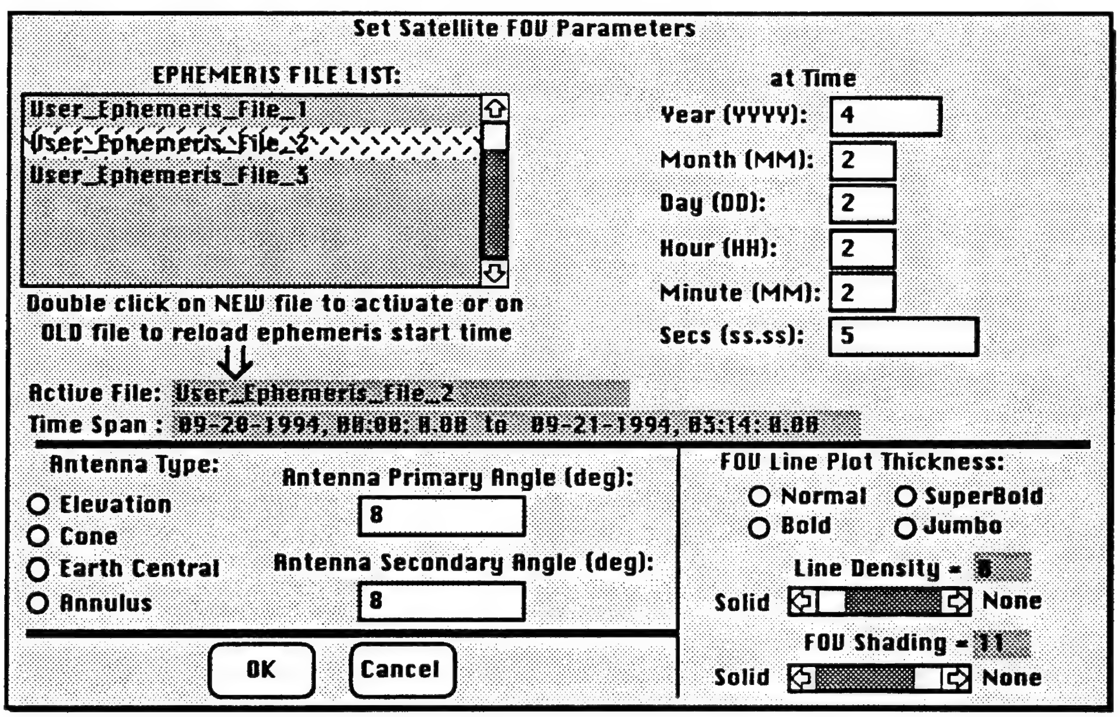

Figure 7-3. Satellite Field-of-View Dialog

(see Figure 7-1). The *Antenna Type* is set from a collection of radio buttons to the lower left of the dialog. The four angle definitions are discussed in Appendix A. The *Secondary Angle* is only required and can only be set for the case of a sensor with a FOV shaped like an *Annulus.* Controls for defining the appearance of the plotted FOV are in the lower right portion of the dialog. The *Line Plot Thickness* can be set using one of the radio buttons provided. This will change the thickness of the exterior line defining the FOV, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. *Line density* is used to change the exterior line from *Solid* through broken (i.e. "dotted line") to *None*, where the line is not displayed. A total of 10 levels is available. The *FOV Shading* scroll is used to select from 12 different levels of density of the shading applied to the area covered by the satellite FOV. All parameters set from the box in the lower right portion of this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all satellite FOV parameters as shown in the dialog.

7.2.2 SATELLITE TRACKS

Figure 7-4. **Satellite Tracks** Menu

The **Satellite Tracks** menu is shown in Figure 7-4, and all its menu options are explained in Section 7.1. This plot command is used to plot the ground track and/or space track over a time interval of an earth-orbiting satellite. The dialog that appears from the **Options** command is shown in Figure 7-5. This dialog is not available to the user unless at least one ephemeris file has been opened (see Section 9.1). A list of files in the active *Ephemeris File List* appears in the scroll list to the left of the dialog. By selecting a file, the user determines which satellite track will be plotted. The first open file is the default selection when this dialog is initially accessed, but a different ephemeris can be selected by double clicking the mouse on the name of the new file in the list. Once selected, the identity of this active file is propagated throughout most of the **Plot** dialogs. To eliminate uncertainty, the name of the active file is displayed in the *Active File* area below the list. The *Start Time* and *Stop Time* are taken from the current active ephemeris file, but may be reset by the user so long as the times are within the confines of the time period covered by the file. The default values of *Start Time* and *Stop Time* are the endpoints of the current active ephemeris file. If the user needs to reinitialize the times on the current active file, that file name can be double-clicked as if it were a re-selection of the ephemeris file. The times displayed in this dialog are linked to the times shown in the **Satellite Swath** menu (see Figure 7-1). Controls for defining the appearance of the plotted FOV are in the lower right portion of the dialog.

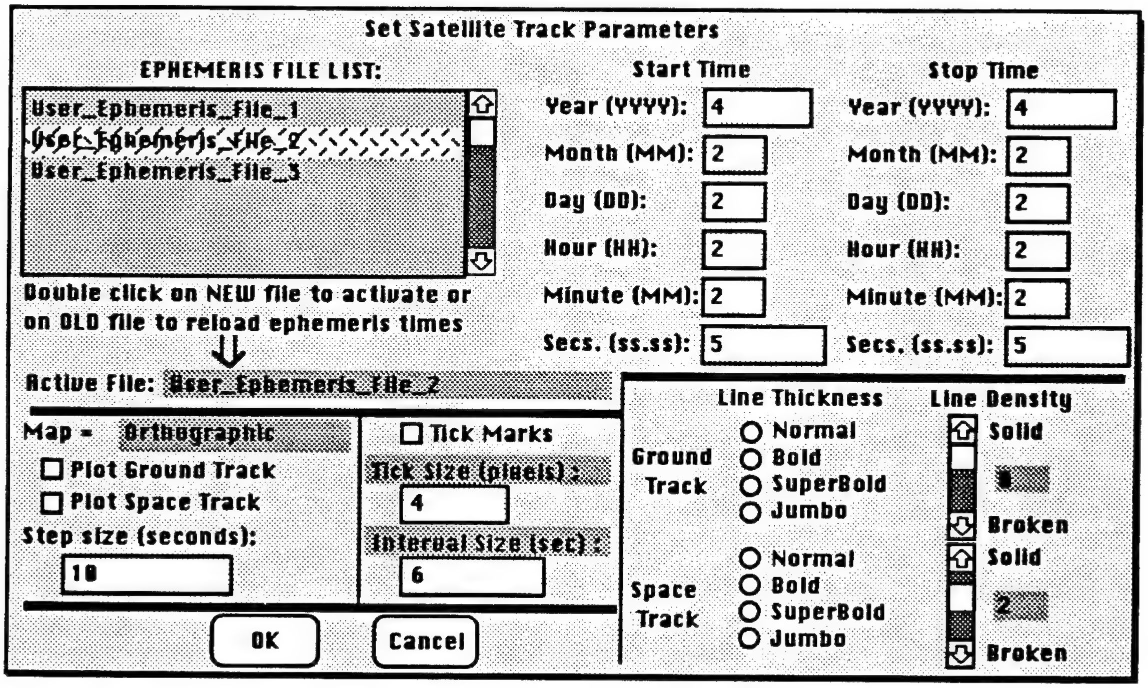

Figure 7-5. Satellite Tracks Dialog

OATS will identify the current *Map* projection. *Plot Space Track* is a viable option only for orthographic or vertical perspective plots, in which case at least one of the ground or space track options must be selected. The *Step Size* is the time interval in seconds between successively plotted points along the track. As plotted tracks consist of a series of connected straight line segments, the smoothness of the plot is a function of step size. A smaller step size implies a smoother plot, but also implies a longer execution. *Step Size* is independent of the ephemeris step size interval. *Tick Marks* to signify time points along the satellite tracks(s) may be flagged on or off. If on, the user may select the *Tick Size* in pixels as well as the interval between ticks. The beginning of the tick intervals coincides with the *Start Time* used for the plot. The *Interval Size* must be an integral multiple of the *Step Size*, otherwise it is adjusted by OATS. Using the radio buttons provided, the *Line Thickness* for ground and space tracks can be set separately to one of four available values. This will change the thickness of the track line, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. The *Line Density* indicates the degree of brokenness of the line used to plot the tracks. A total of 10 levels is available. Density is also a function of the *Step Size*. Both *Line Thickness* and *Line Density* can be used when presenting multiple orbits on the same plot to distinguish between the various presented tracks. All parameters set from the box in the lower right portion of this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all satellite track parameters as shown in the dialog.

7.2.3 SATELLITE POSITION

Figure 7-6. **Satellite Position** Menu

The **Satellite Position** menu is shown in Figure 7-6, and all its menu options are explained in Section 7.1. This plot command is used to plot a satellite icon at the geographic and/or space positions for a user-selected time based on whichever of the ephemeris files is active and depending on the map projection in use. Satellite icons are shown in Figure 7-7 The dialog that results from the **Options** command appears in Figure 7-8. This dialog is not available to the user unless at least one ephemeris file has been opened

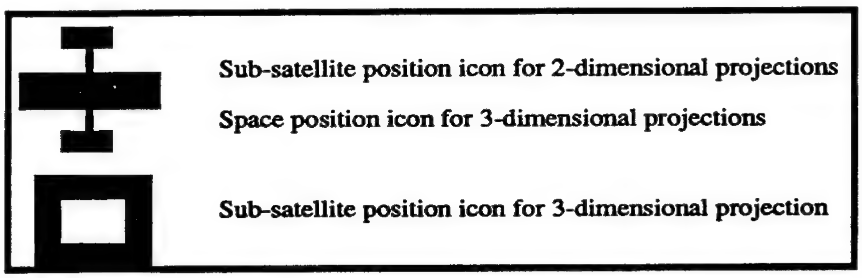

Figure 7-7. Satellite Position Icons

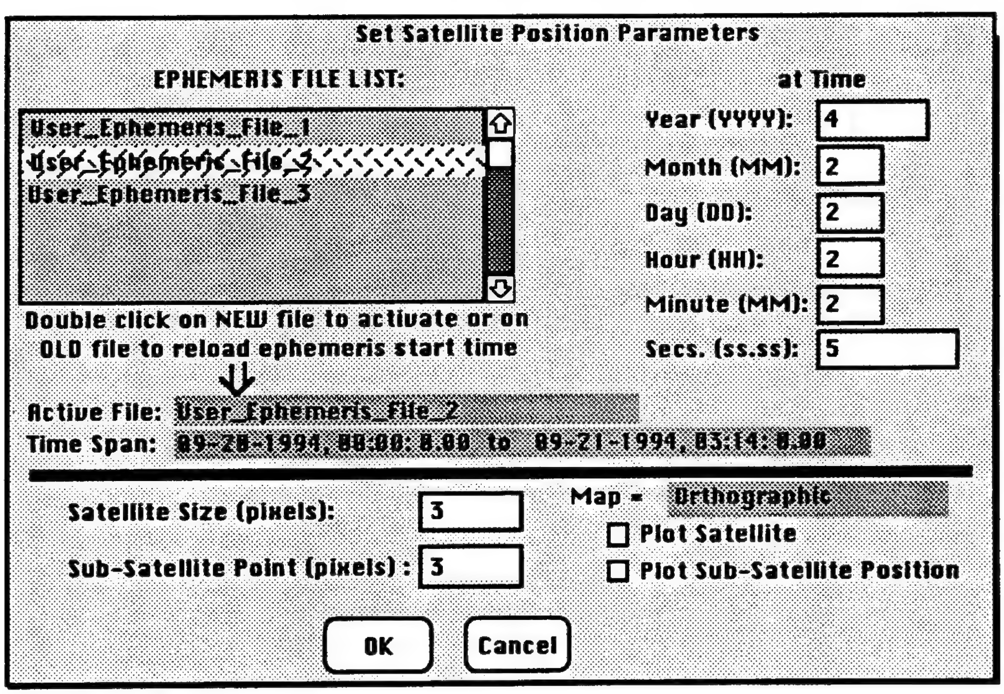

Figure 7-8. Satellite Position Dialog

(see Section 9). A list of files in the active *Ephemeris File List* (i.e. open files) appears in the scroll list to the left of the dialog. The first open file is the default selection when this dialog is initially accessed, but a different ephemeris can be selected by double clicking the mouse on the name of the new file in the list. Once selected, the identity of this active file is distributed to most of the **Plot** dialogs. To eliminate ambiguity, the name of the active file is displayed in the *Active File* area below the list. The *Time* from the ephemeris at which the position(s) will be plotted is displayed in the *Year, Month, Day, Hour, Minute*, and *Secs* fields to the upper right of the dialog. The time is defaulted to the beginning of the ephemeris file, but can be reset by the user to any time during the interval covered by the file. As an aid in resetting the *Time*, the *Time Span* is displayed and shows the limits covered by the current active file. The *Time* displayed in this dialog is linked to the time shown in the **Satellite Field-of-View** and **Sun & Shadows** menu items (see Figure 7-1). OATS will identify the current *Map* projection. For two-dimensional map projections, *Satellite Size* and *Plot Satellite* are active and will by definition plot the sub-satellite position. For three-dimensional projections, *Satellite Size* and *Plot Satellite* refer to the space position of the satellite. The *Sub-Satellite Position* and its pixel size are also active. At least one of the ground or space position options must be selected. All parameters set from the box in the lower portion of this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all satellite position parameters as shown in the dialog.

7.2.4 SATELLITE SWATH

Figure 7-9. **Satellite Swath** Menu

The **Satellite Swath** menu is shown in Figure 7-9, and all its menu options are explained in Section 7.1. This plot command is used to plot the swath swept out by the satellite FOV over a time interval by an earth-orbiting satellite. The dialog that results from the **Options** command appears in Figure 7-10. This dialog is not available to the user unless at least one ephemeris file has been opened. A list of files in the active *Ephemeris File List* (i.e. open files) appears in the scroll list to the left of the dialog. The satellite swath is plotted from whichever of these files is active. The first open file is the default selection when this dialog is initially accessed, but a different ephemeris can be selected by double clicking the mouse on the name of the new file in the list. Once selected, the identity of this active file is propagated throughout most of the **Plot** dialogs. To eliminate ambiguity, the name of the active file is displayed in the *Active File* area below the list. The *Start Time* and *Stop Time* are taken from the current active ephemeris file, but may be

reset by the user so long as the times are within the confines of the time period covered by the file. The default values of *Start Time* and *Stop Time* are the endpoints of the current active ephemeris file. If the user needs to reinitialize the times on the current active file, that file name can be double-clicked as if it were a re-selection of the ephemeris file. The times displayed in this dialog are linked to the times shown in the **Satellite Tracks** menu (see Figure 7-1). Controls for defining the appearance of the plotted swath are in the lower right portion of the dialog.

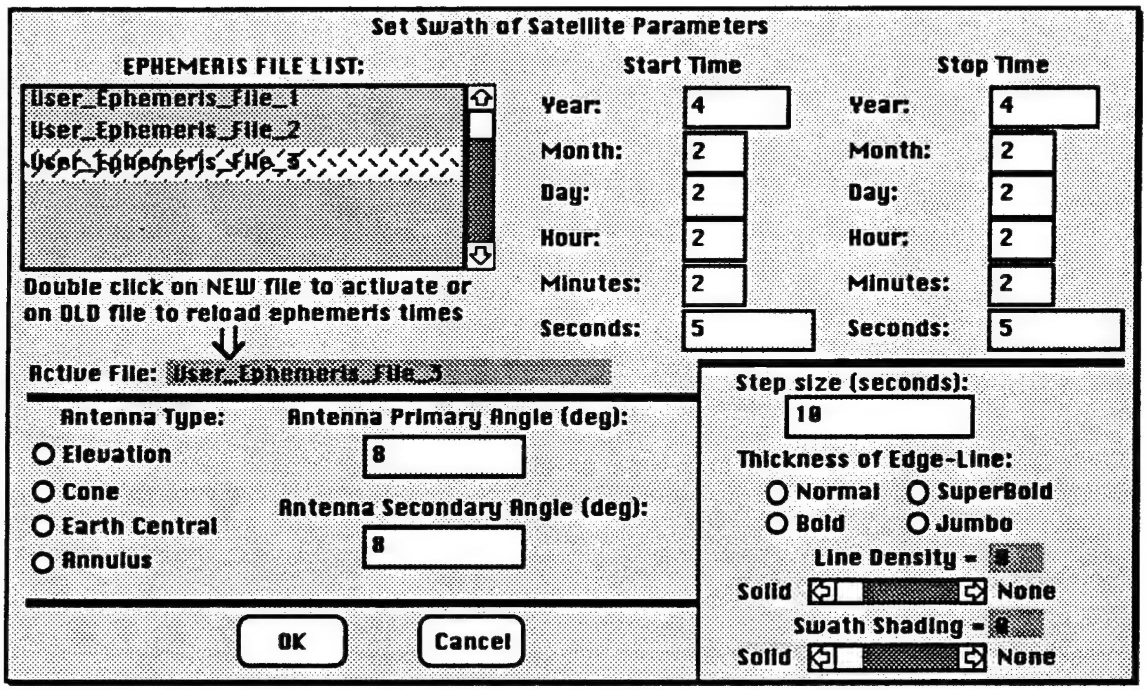

Figure 7-10. Satellite Swath Parameters Dialog

The *Step Size* is the time interval in seconds between successive computations of area covered along the satellite track. As plotted tracks (and the swath that they imply) consist of a series of connected straight line segments, the smoothness of the plot is a function of step size. A smaller step size implies a smoother plot, but also implies a longer execution. *Step Size* is independent of the ephemeris step size interval. The *Antenna Type* is set from a collection of radio buttons to the lower left of the dialog. The four angle definitions are discussed in Appendix A. The *Secondary Angle* is only required and can only be set for the case of a FOV shaped like an *Annulus*. Controls for defining the appearance of the plotted swath are in the lower right portion of the dialog. The *Line Plot Thickness* can be set using one of the radio buttons provided. This will change the thickness of the exterior line defining the swath, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. *Line density* is used to change the exterior line from *Solid* through broken (i.e. "dotted line") to *None*, where the line is not displayed. A total of 10 levels is available. As most plotted satellite swaths will overlap themselves at some point, the user should note that only the most recent orbit's swath will fully display the bounding edge lines. Edge lines

drawn early in the orbit will be overwritten. The *Swath Shading* scroll is used to select from 12 different levels of the density of the shading applied to the area covered by the satellite swath. All parameters set from the box in the lower right portion of this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all satellite swath parameters as shown in the dialog.

7.2.5 TARGET POSITION

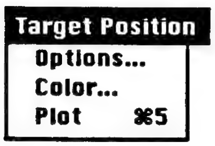

Figure 7-11. **Target Position** Menu

The **Target Position** menu is shown in Figure 7-11, and all its menu options are explained in Section 7.1. This plot command is used to plot a set of target icons at user-defined geographic positions. The target icon is shown in Figure 7-12. Up to 100 targets may be plotted with a single **Plot** command.

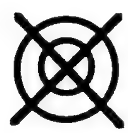

Figure 7-12. Target Position Icon

The dialog that results from the **Options** command appears in Figure 7-13. This dialog is an interactive interface designed to allow the user to add, select, and display target data. It contains two target lists, one cataloged and one active. The cataloged list is also utilized in the **Coverage** menu (see Section 8). The *Cataloged Target List* is maintained between executions of OATS, and is intended to serve as a quasi-permanent list of targets for some user-defined overall scheme of coverage analysis. The *Active Target List* is wiped clean between OATS executions, and is intended as a dynamic and frequently changed list of targets for individual **Plot** commands. Each of these lists is displayed as a scroll list in the interface, along with a count of the number of objects in that list at the top of the list. Because the cataloged list is characteristically used as a source of objects for the active list, the *Select* and *ALL Select* buttons move objects from cataloged to active. The *Select* button moves one item which has been highlighted with a single mouse click, while the *ALL Select* moves every item. Each list has a *Clear* button to eliminate all objects in the list, and a *Delete* button that will eliminate a single object that has been highlighted by a mouse click. The flexibility of this interface is enhanced by the *OPEN File* and *SAVE File* buttons, which allow an external list of targets to be read into or created from the cataloged list. The format for the target list files is covered in Section 10.3. It is a simple and straightforward format, which implies that a target

list can be created by external software. An easy way to create an external target file might be with an editor.

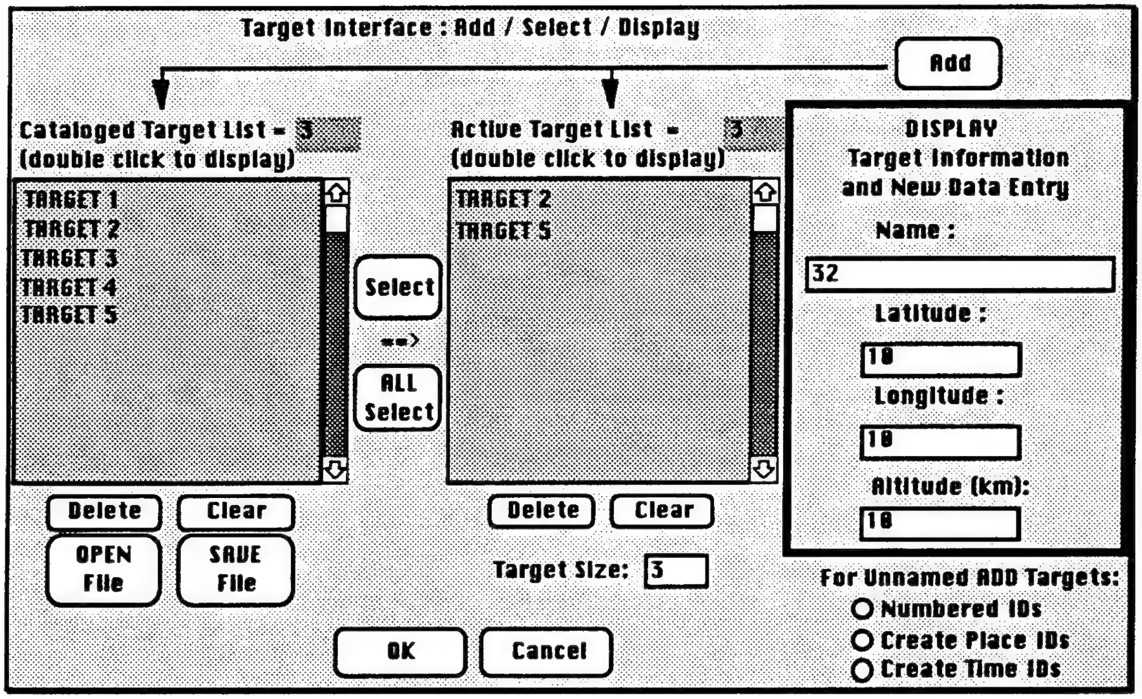

Figure 7-13. Target Interface Dialog

To the right of the dialog interface is a *DISPLAY* block for the individual target data. Relevant data fields include the *Name*, geodetic *Latitude* and *Longitude*, and *Altitude*. For targets already in either the active or cataloged list, data can be displayed by double clicking on the target name in the scroll list. The DISPLAY fields can also be used in conjunction with the *Add* button in the upper right of the interface to interactively one-at-a-time create a list of targets. Data is first manually entered into each of the four data fields. Pushing the *Add* button will then enter the new target data into each of the active and cataloged lists. Each target must have some type of name in order to clearly show its existence in the scroll lists; however, there is a great deal of flexibility built into OATS with regard to target name conventions. It is expected that targets may change frequently and that there may be no clearly unique place name associated with a target. Target names may be any non-blank field, including a simple numerical digit(s) as well as any combination string of alphanumerics. Target names may even be repeated as long as the qualifying latitude, longitude, and altitude are not all identical. When using the *Add* feature, OATS has provision for automatically naming targets. If the *Name* field is left blank, a name will be generated according to the settings for the radio buttons in the lower right corner of the interface and attached to the new target. Available schemes and examples of each include:

TYPE	EXAMPLE	DESCRIPTION
Numbered	TARG_0001	for target numbers 1 through 9999
Place ID	TARG_+1241_12386	for a target at latitude +12.41° and longitude 123.86°
Time ID	TARG_23-DEC-94_09:25:18	for a target created at 9:25:18 AM on December 23, 1994 (labeled according to Macintosh internal clock)

The last parameter which can be set from this dialog is the *Target Size* (in pixels) used to plot targets. Note that values which are too small will result in a warning message because the target icon will become unrecognizable below a threshold. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog (including changes in the scroll lists), while *OK* will set all satellite target parameters as shown in the dialog.

7.2.6 GROUND STATION POSITION

Figure 7-14. **Ground Station Position** Menu

The **Ground Station Position** menu is shown in Figure 7-14, and all its menu options are explained in Section 7.1. This plot command is used to plot a set of ground station icons at user-defined geographic positions. The ground station icon is shown in Figure 7-15. Up to 20 ground stations may be plotted with a single **Plot** command.

Figure 7-15. Ground Station Position Icon

The dialog that results from the **Options** command appears in Figure 7-16. This dialog is an interactive interface designed to allow the user to add, select, and display ground station data. It contains two station lists, one cataloged and one active. The cataloged list is also utilized in the **Coverage** menu (see Section 8). The *Cataloged G.S. List* is maintained between executions of OATS, and is intended to serve as a quasi-permanent list of ground stations for some user-defined overall scheme of coverage analysis. The *Active G.S. List* is wiped clean between OATS executions, and is intended as a dynamic and frequently changed list of stations for individual **Plot** commands. Each of these lists is displayed as a scroll list in the interface, along with a count of the number of objects in that list at the top of the list. Because the cataloged list is characteristically used as a source of objects for the active list, the *Select* and *ALL Select*

buttons move objects from cataloged to active. The *Select* button moves one item which has been highlighted with a single mouse click, while the *ALL Select* moves every item. Each list has a *Clear* button to eliminate all objects in the list, and a *Delete* button that will eliminate a single object that has been highlighted by a mouse click. The flexibility of this interface is enhanced by the *OPEN File* and *SAVE File* buttons, which allow an external list of ground stations to be read into or created from the cataloged list. The format for the ground station list files is covered in Section 10.4. It is a simple and straightforward format, which implies that a station list can be created by external software. An easy way to create an external ground station file might be with an editor.

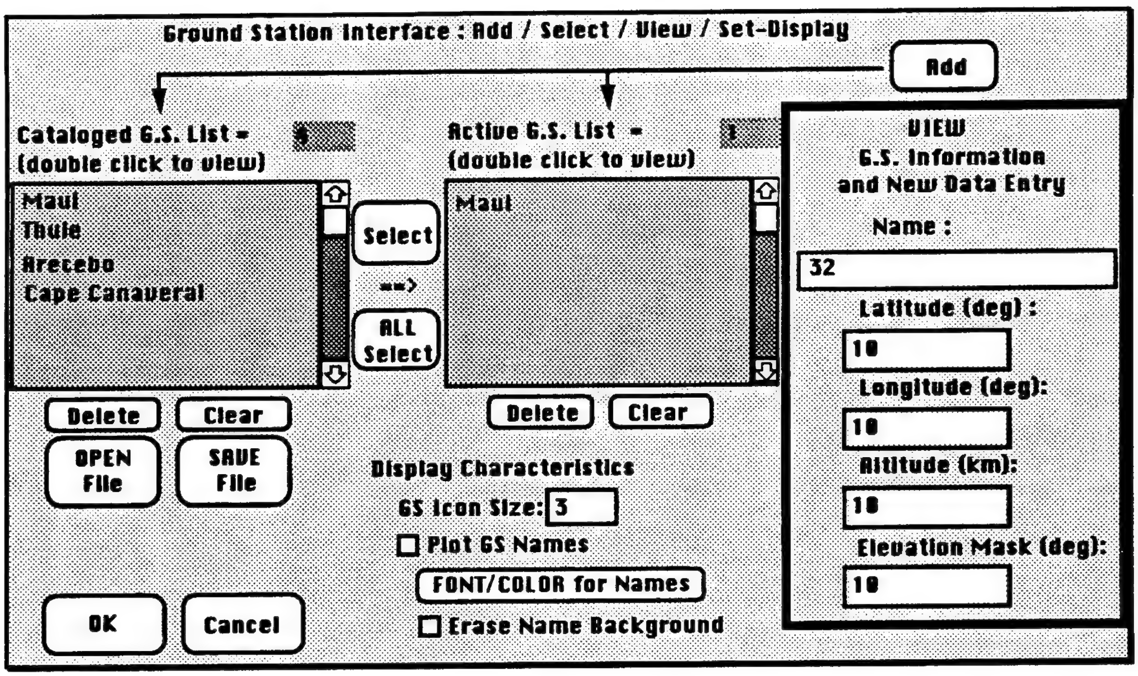

Figure 7-16. Ground Station Position Interface Dialog

To the right of the dialog interface is a *VIEW* block for the individual ground station data. Data fields include the *Name*, geodetic *Latitude* and*Longitude*, *Altitude*, and the *Elevation Mask*. For stations already in either the active or cataloged list, data can be displayed by double clicking on the station name in the scroll list. The *VIEW* fields can also be used in conjunction with the *Add* button in the upper right of the interface to interactively one-at-a-time create a list of ground stations. Data is first manually entered into each of the five data fields. Pushing the *Add* button will then enter the new ground station data into each of the active and cataloged lists. Each station must have some type of name in order to clearly show its existence in the scroll lists; however, there is a great deal of flexibility built into OATS with regard to naming conventions. Station names may be any non-blank field, including a simple numerical digit(s) as well as any combination string of alphanumerics. Names may even be repeated as long as the qualifying latitude, longitude, altitude, and mask are not all identical.

The ground station interface allows the user to control the size of the plotted *GS Icon Size* in pixels. Note that values which are too small will result in a warning message because the ground station icon will become unrecognizable below a threshold. Ground stations can also automatically have their names plotted when the station icons are plotted. The *Plot GS Names* checkbox turns name plotting on and off. The *FONT/COLOR for Names* button is active only if name plotting is active. This button brings up the dialog shown in Figure 3-6 and discussed in Section 3.5, and allows the user to control the color of the plotted ground station names as well as their font and print style. Note that the underline style has been disabled in OATS for aesthetic reasons, even though this will not be apparent from the standard FACEIT utility dialog. *Erase Name Background* allows the user the option of eliminating all plotted information from behind the plotted ground station name, a feature that can be useful if background clutter makes the names illegible. If the user elects to plot ground station names, it should be noted that this is one instance when OATS must combine all layers before performing the plot and that the single layer of ground station icons plus names cannot be removed without deleting the entire background. As a more flexible but more time-consuming alternative to automatic name plotting, names can be annotated manually using the technique discussed in Section 5.5.

The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog (including changes in the scroll lists), while *OK* will set all ground station plot parameters as shown in the dialog.

7.2.7 GROUND STATION FIELD-OF-VIEW

Figure 7-17. **Ground Station FOV** Menu

The **Ground Station Field-of-View** menu is shown in Figure 7-17, and all its menu options are explained in Section 7.1. This plot command is used to plot the field-of-view around every ground station in the Active Ground Station List (see Section 7.2.6). The dialog that results from the **Options** command appears in Figure 7-18.

A ground station FOV must be linked to a satellite altitude. OATS provides two methods of selecting this altitude for the ground station FOVs. The user may use the radio buttons at the top of this dialog to select a *Fixed Value of Satellite Altitude* or an *Altitude Determined from Time of Satellite Position*. If a fixed value is selected, the user manually inputs the satellite altitude in kilometers. If the satellite position is used, the

altitude is derived from the time and location implied by the satellite position dialog (see Section 7.2.3) or the satellite FOV dialog (see Section 7.2.1). Because satellite position depends on an ephemeris file, a warning will be issued if the *Time of Satellite Position* option is selected without setting the time appropriately.

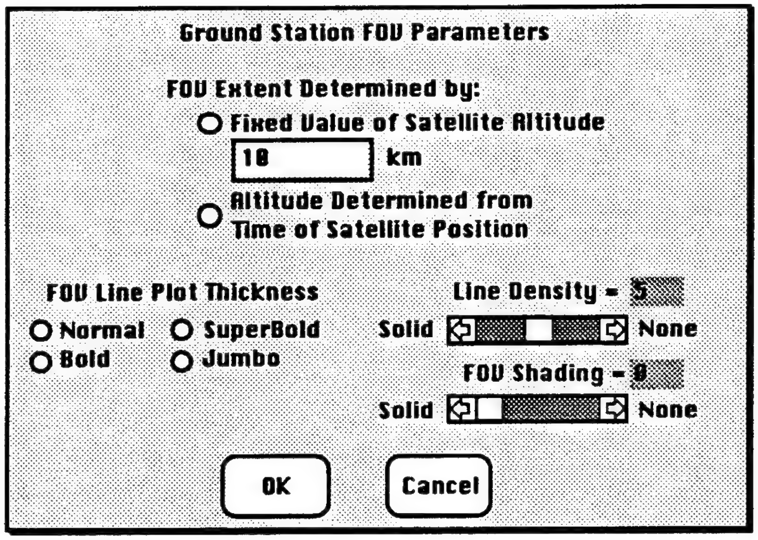

Figure 7-18. Ground Station FOV Dialog

Controls for defining the appearance of the plotted FOV are in the lower half of the dialog. The *Line Plot Thickness* can be set using one of the radio buttons provided. This will change the thickness of the exterior line defining the FOV, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. *Line density* is used to change the exterior line from *Solid* through broken (i.e. "dotted line") to *None*, where the line is not displayed. A total of 10 levels is available. The *FOV Shading* scroll is used to select from 12 different levels of the density of the shading applied to the area covered by the ground station FOV. All parameters set from this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all ground station FOV parameters as shown in the dialog.

7.2.8 DENSITY CONTOURS

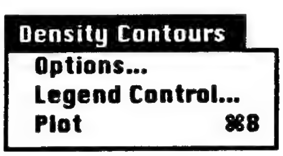

Figure 7-19. **Density Contours** Menu

The **Density Contours** menu is shown in Figure 7-19. Density contours are solid area shadings using colors over a world-wide mesh to show satellite coverage by the color value in each mesh element. These

area contours are based on a user defined set of ephemeris files, antenna settings, and ground stations. The **Plot** command issued from this menu will plot the computed satellite coverage values contained in a file derived using the **Coverage** menu as discussed in Section 8.2.2. It is strongly suggested that first time users master the techniques needed to produce this file before proceeding with plotting of density contours. OATS is also capable of plotting density contours for an externally created file with the proper format. Formats for both external and internal contour files are discussed in Section 10.7. Choice of the **Plot** command will first bring up a standard Macintosh interface from which the user must select a computed coverage file. If the file does not have expected OATS-file formatting, an alert message will appear to inform the user that the file will be treated as an external contour file. The product color mapping will be plotted overlying any data previously existing in the Graphics Window. A continental outline map (see Section 7.3) makes a very effective background for a density contour plot. Because colors are additive, it is recommended that density plots be made over maps using a white background with all line colors set to black.

7.2.8.1 Density Contour **Options**

The dialog that results from the **Options** command appears in Figure 7-20. It is designed as an interactive interface to allow the user to set the parameters and colors employed when plotting density contours. Central to this interface is a non-standard scroll list of the contour values and a swatch of their associated color. Contouring is performed such that each level listed represents a range of coverage values, with the value shown equaling the lowest end of the range for a given color. The control buttons to the right of the color/value scroll list are used to modify the contour values, and the control buttons to the left of the list are used to modify the colors associated with the values. Each color value has a small button with a letter. These letters are used as local IDs within the scroll list, and are required when modifying a single color/value. At the top of the scroll list are buttons that allow the user to *Scroll Up* though the list one value at a time or to go directly to the *Top* of the list of values. Similarly, at the bottom of the scroll list are buttons that allow the user to *Scroll Down* though the list one value at a time or to go directly to the *Bottom* of the list of values. The number of coverage values in the scroll list is displayed at the top of the list.

To plot density contours, the user must first select the *Contour Type* from the radio buttons in the upper right corner of the interface dialog. All five possible type are available in the files produced by the **Coverage** menu. The *Average Outage* and *Maximum Outage* are given in terms of minutes per day that a mesh region is not covered (i.e. outage means mesh region is "out of view"). The *Cumulative Coverage* (time mesh region is in view) can be expressed as a *Percentage of Time*, as the *Average Daily Coverage* in minutes, or as the *Total Coverage* in minutes.

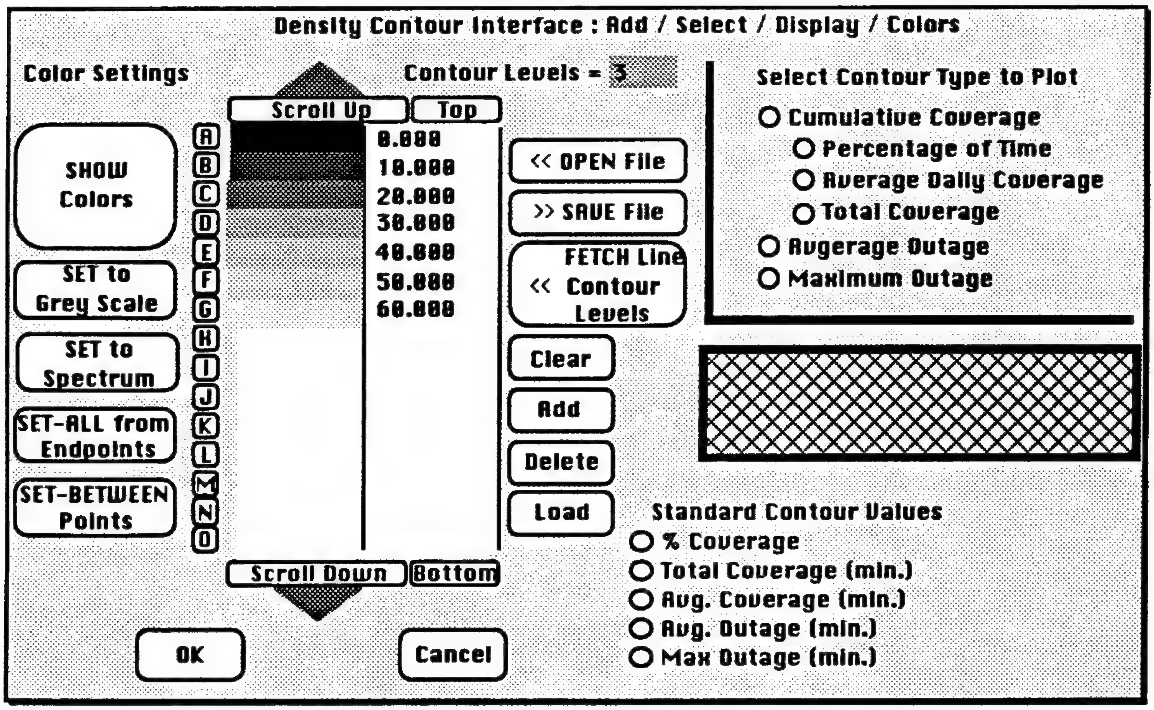

Figure 7-20. Density Contour Interface Dialog

Contour values can be loaded into the scroll list in a variety of ways. The *Load* button will retrieve one of five sets of *Standard Contour Values* that are selected by radio buttons at the bottom of the interface. These sets of standard values are maintained along with their color settings in OATS largely as a service to first-time OATS users who are uncertain of what a good set of contour values might be. They are a good starting point for a set of coverage values, which the user can then adjust to his own needs. Values can be retrieved from an external file by an *OPEN File* command (see Section 10.6 for file formats). Correspondingly, a favorite set of values in the scroll list can be saved to a file using the *SAVE File* button. OATS also performs line contour (see Section 7.2.9) plots, which use a separate data base of contour values than those used for density contour plotting. If desired, the density contour values can be set equal to the line contour values with the *FETCH Line Contour Levels* button. *Clear* will eliminate all values in the scroll list. *Delete* will bring up the supplemental *Delete Level ID* dialog shown in Figure 7-21, which can be used to enter the single character local ID found to the left of the color swatches. The *Add* button allows the user to enter single new contour values with the supplemental *Value to Add* dialog seen in Figure 7-21. Whenever a new value is added to the color/value list, the list is sorted by value and the color of the new value is set to gray.

Color swatches are not seen when the dialog is first brought up, and are not seen until the *SHOW Colors* button is used to make them visible. Each color can be set individually with the lettered local ID button.

These buttons will bring up the utility dialog seen in Figure 3-5 and discussed in Section 3.5, which can be used to select a color for the single swatch. The *SET to Gray Scale* button will convert all color swatches to a set of gray values running from black to white. The *SET to Spectrum* will convert all color swatches to a set of pre-selected color swatches running through the rainbow colors of red, orange, yellow, green, blue, and violet. There is an upper limit of 16 colors available in this fashion. After setting the single colors at the top and bottom of the scroll list, the full range of colors can be set using the *SET-ALL from Endpoints* button. This could be used for instance to set color swatches ranging from white to blue with interpolated values between the extremums. In a similar fashion but on a smaller scale, the *SET-BETWEEN Points* button can be used to interpolate colors between any two color/values. The *Letter IDs of Endpoints* dialog seen in Figure 7-21 will be displayed, allowing the user to enter any two local IDs to use as endpoints in the color interpolation.

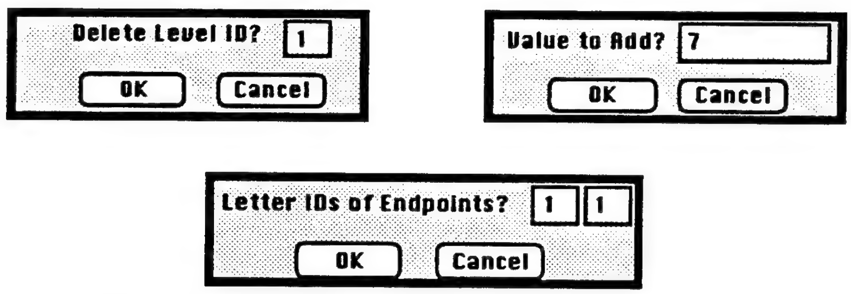

Figure 7-21. Density Contour Interface Supplemental Dialogs

All parameters set from this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this menu, while *OK* will set all density contour parameters as shown in the dialog.

7.2.8.2 Density Contour **Legend**

The dialog that comes up with the **Legend** command appears in Figure 7-22. It is used to provide control over the appearance of the legend that describes the density contours. The most basic control comes from a pair of radio buttons under *Legend Display* that turn the legend *On* or *Off*. The *Legend Location* allows the user to manually set the position of the legend by specifying the location in pixels of the *Top* and *Left* corner of the legend box. The *Set to Default* button will compute default values for the legend position settings, which will place the legend box in the upper left corner of the user's plot. Each level will have a color swatch and a value like those seen in the dialog in Figure 7-20. Labeling of the swatch values can be *As INTEGER Values* or *As FLOATING PT Values*, according to the settings of the radio buttons provided. The *FONT Set* button will call up the utility dialog seen in Figure 3-6 to allow the user to set the color and style of the value labels. All parameters set from this dialog are preserved between executions of OATS.

The *Cancel* button will return to the main menu without recording any of the parameter changes made in this menu, while *OK* will set all legend parameters as shown in the dialog.

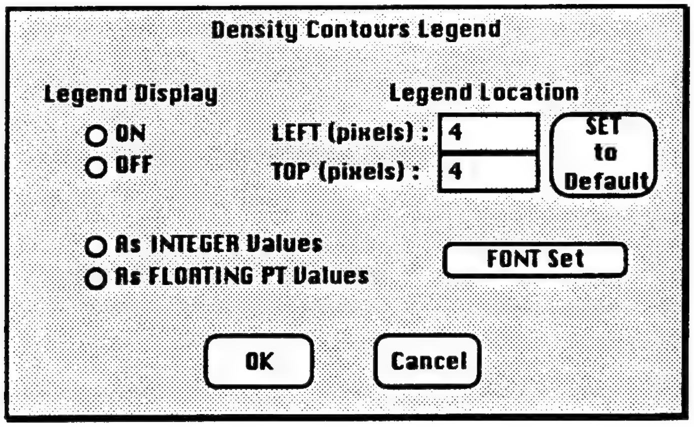

Figure 7-22. Density Contour Legend Dialog

7.2.9 Line Contours

Figure 7-23. **Line Contours** Menu

The **Line Contours** menu is shown in Figure 7-23, and all its menu options are explained in Section 7.1. Line contours are isochrones connecting elements of a world-wide mesh that show satellite coverage by value of each mesh element. These line contours are based on a user defined set of ephemeris files, antenna settings, and ground stations. The **Plot** command issued from this menu will plot the computed satellite coverage values contained in a file derived using the **Coverage** menu as discussed in Section 8.2.2. It is strongly suggested that first time users master the techniques needed to produce this file before proceeding with plotting of line contours. OATS is also capable of plotting line contours for an externally created file with the proper format. Formats for both external and internal contour files are discussed in Section 10.7. Choice of the **Plot** command will first bring up a standard Macintosh interface from which the user must select a computed coverage file. If the file does not have expected OATS-file formatting, an alert message will appear to inform the user that the file will be treated as an external contour file. The line contours will be plotted overlying any data previously existing in the Graphics Window.

The dialog that results from the **Options** command appears in Figure 7-24. It is designed as an interactive interface to allow the user to set the parameters employed when plotting line contours. Central to this interface is a standard scroll list of the contour values. Contouring is performed such that each level

listed represents a range of coverage values, with the value shown equaling the lowest end of the range for a given level. The control buttons to the right of the scroll list are used to modify the contour values. The number of coverage values in the scroll list is displayed at the top of the list. To plot line contours, the user must first select the *Contour Type* from the radio buttons in the upper right corner of the interface dialog. All five possible types are available in the files produced by the **Coverage** menu. The *Average Outage* and *Maximum Outage* are given in terms of minutes per day that a mesh region is not covered (i.e. outage means mesh region is "out of view"). The *Cumulative Coverage* (time mesh region is in view) can be expressed as a *Percentage of Time*, as the *Average Daily Coverage* in minutes, or as the *Total Coverage* in minutes.

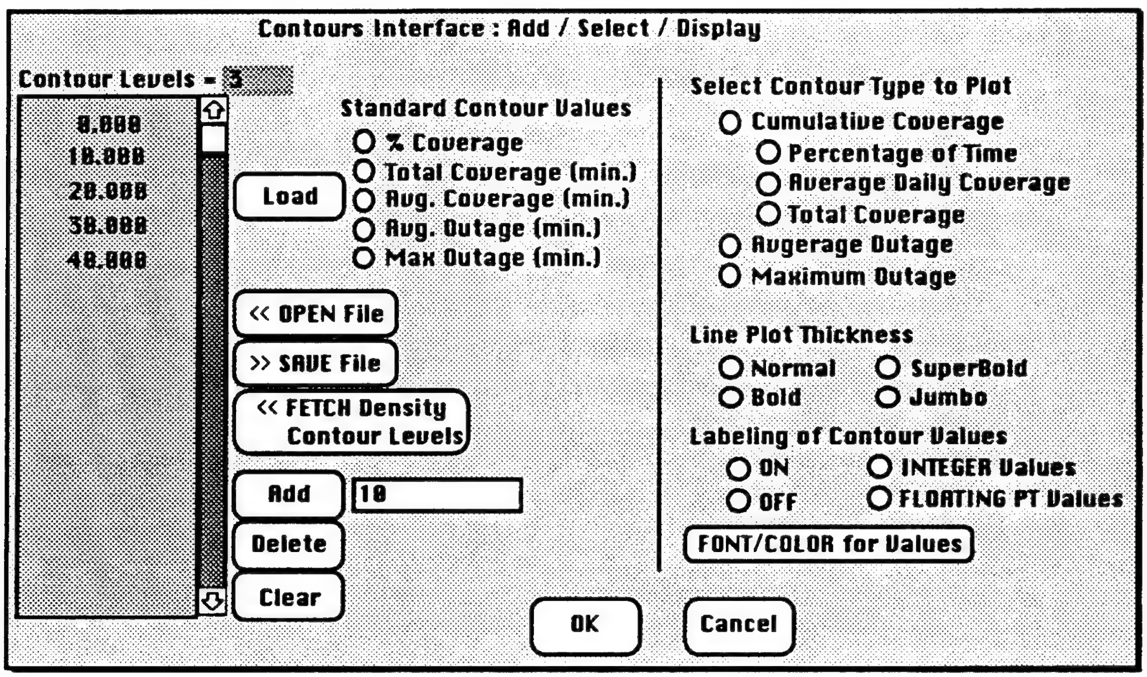

Figure 7-24. Line Contour Interface Dialog

Contour values can be loaded into the scroll list in a variety of ways. The *Load* button will retrieve one of five sets of *Standard Contour Values* that are selected by radio buttons. These sets of standard values are maintained in OATS largely as a service to first-time OATS users who are uncertain of what a good set of contour values might be. They are a good starting point for a set of coverage values, which the user can then adjust to his own needs. Values can be retrieved from an external file by an *OPEN File* command (see Section 10.6 for file formats). Correspondingly, a favorite set of values in the scroll list can be saved to a file using the *SAVE File* button. OATS also performs density contour (see Section 7.2.8) plots, which use a separate data base of contour values than those used for line contour plotting. If desired, the line contour values can be set equal to the density contour values with the *FETCH Density Contour Levels* button.

Clear will eliminate all values in the scroll list. Single values can be eliminated from the levels list by highlighting a level with a mouse click and then clicking the *Delete* button. The *Add* button allows the user to enter a single new contour value which has been entered manually into the input field provided. Whenever a new value is added to the values list, the list is sorted in ascending order.

Controls defining the appearance of the plotted line contours are in the lower right corner of the dialog. The *Line Plot Thickness* can be set using one of the radio buttons provided. This will change the thickness of the coverage isochrones, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. OATS makes provision for the user to label the line contours for identification purposes. *Labeling of Contour Values* can be turned *ON* or *OFF*, and they can be shown as *INTEGER Values* or as *FLOATING PT Values* using the radio button settings. The *FONT Set* button will call up the utility dialog seen in Figure 3-6 to allow the user to set the color and style of the value labels. The user should note that this labeling is intended as supplemental information and that little effort has been made to make the labeling algorithm robust. One label only is provided for each isochrone. A more aesthetically pleasing result can be achieved using the techniques discussed in Section 5.5.

All parameters set from this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all line contour parameters as shown in the dialog.

7.2.10 SUN AND SHADOWS

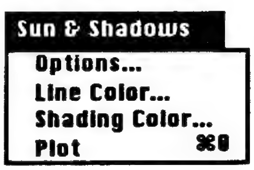

Figure 7-25. **Sun and Shadows** Menu

The **Sun and Shadows** menu is shown in Figure 7-25, and all its menu options are explained in Section 7.1. This plot command is used to display a sun icon, shown in Figure 7-26, at the geographic sub-solar position. The plot command will also show the terminator line, defined lines of twilight, and the area of the earth's surface in shadow.

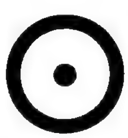

Figure 7-26. Solar Icon

The dialog that results from the **Options** command appears in Figure 7-27. Checkboxes are available to separately turn on or off the *Sub-Solar Position, Terminator Line, Astronomical Twilight Line, Civilian Twilight Line*, and *Shadowed Region*. Next to the position checkbox is an input field which is used to set the *Sub-Solar Point Size* in pixels. Note that values which are too small will result in a warning message when the dialog is exited because the solar icon will become unrecognizable below a threshold. The *Time* displayed in this dialog and used for plotting sun-related features is linked to the time shown in the **Satellite Field-of-View** and **Satellite Position** menu items (see Figure 7-1); however, the time can of course be reset manually. The *Time* is displayed in the *Year, Month, Day, Hour, Minute*, and *Secs* fields to the upper right of the dialog. Controls for defining the appearance of the plotted shadows and sun-defined lines are in the lower portion of the dialog. The *Line Plot Thickness* can be set using one of the radio buttons provided. This will change the thickness of all sun lines, and ranges from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. *Line density* is used to change the sun lines from *Solid* through broken (i.e. "dotted line"). A total of 10 levels is available. Unlike other dialogs in this **Plot** family, if no line is desired it is controlled by the previously described checkboxes. The *Region Shading* scroll is used to select from 12 different levels of the density of the shading applied to the area covered by shadow. All parameters set from this dialog except *Time* are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all satellite swath parameters as shown in the dialog.

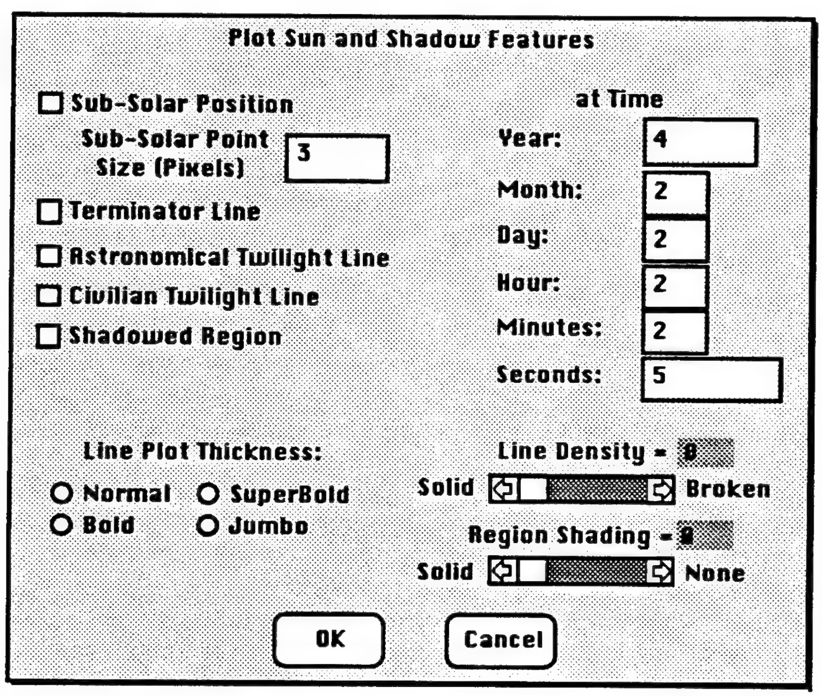

Figure 7-27. Sun and Shadows Dialog

7.3 MAP MENU

Plotting maps is an important part of OATS function because a global map almost always forms the background against which graphic coverage results are plotted. The locations of satellites, targets, and ground stations that contribute to the overall scheme of a potential coverage situation are more easily conceptualized if displayed relative to a map. Often the potential implications of a particular orbit are more easily seen if viewed from an appropriately selected perspective.

Figure 7-28. **Map** Menu

Plotting and control of maps in OATS is controlled with the **Map** menu, as displayed in Figure 7-28. **Map** is available from the **Plot** menu shown in Figure 7-1. There are five menu selections from which to choose for control and plotting of maps.

Projections

This command allows the user to select the map projection for an OATS plot. A map projection is the systematic mathematically defined representation of all or part of the surface of a three-dimensional spherical body (the Earth in this case) on a two-dimensional surface (paper or computer screen). All map projections will produce some level of distortion of map features, with the distortion occurring in map characteristics like area, shape, or scale. The map projection employed is usually selected based upon which distortion it is most critical to minimize. The **Projections** command will produce the dialog shown in Figure 7-29, which presents defining parameters for the six map projections available in OATS. A brief description of each map projection is provided below, with further details available in Reference 6. Each of the six map projections can be selected via the radio button next to its name, which will also deactivate the input parameters for all other projections. Figure 7-30 presents a sample plot from each of the map projections. All parameters set from this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this menu. *OK* will normally set all map projection parameters as shown in the dialog and return to the main menu, with one exception. If a*Vertical Perspective* map projection using a *Satellite Ephemeris* is selected, a different exit path is employed as described below.

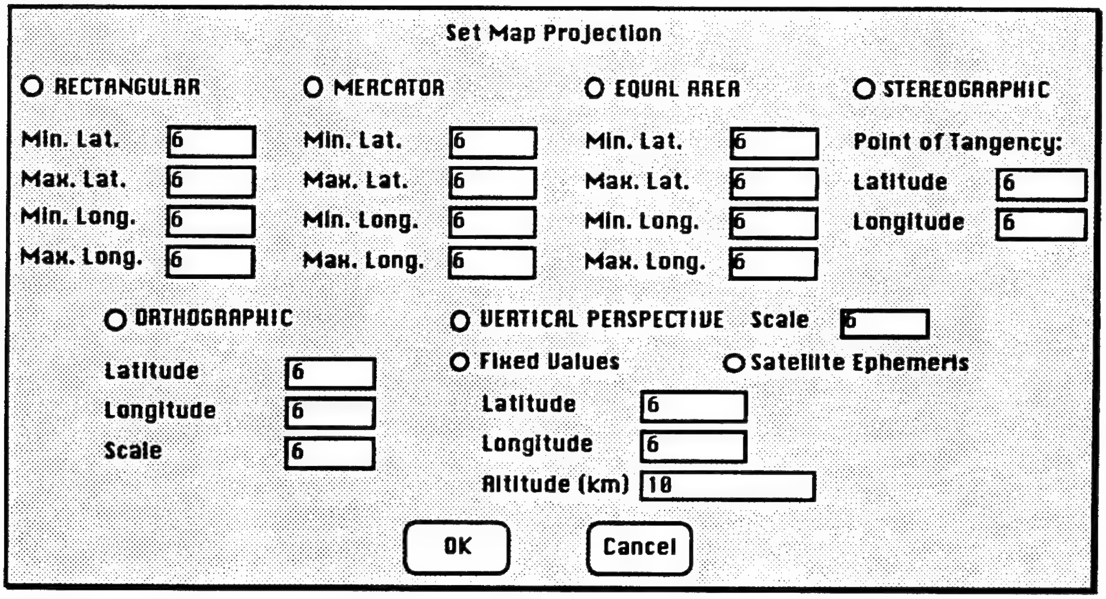

Figure 7-29. Map Projection Dialog

- *Rectangular* - This projection is the first of three OATS cylindrical projections, so named because they are from a family of transformations formed by projecting the earth's surface onto a cylinder wrapped around the sphere at the Equator. Such map projections have a conceptual cut along which the projection-cylinder is cut and then unrolled onto the flat surface. The Rectangular Projection (also known as Equidistant Cylindrical) makes no attempt to minimize any map distortion; however, it is the simplest map projection to construct and understand because latitude and longitude are presented as equally scaled Cartesian coordinates. OATS requires the minimum and maximum of latitude and of longitude to define this projection. All cylindrical longitudes should fall between -360 and +360 degrees and should not exceed a total range of 360 degrees. Rectangular latitude should not exceed -90 or +90 degrees. Parameters that violate these bounds will cause an alert on exit of the dialog, and will result in uncertain results in subsequent plots. OATS defines Rectangular plots such that in a square Graphics Window, the latitude scale equals the longitude scale implied by the user's choice of bounds.
- *Mercator* - The Mercator projection is another cylindrical map projection that preserves map scale near the Equator. OATS requires the minimum and maximum of latitude and longitude to define this transform. Two major drawbacks of the Mercator projection are that there is significant area distortion near the poles, and that the poles themselves are an infinite distance from the Equator because vertical distance is scaled according to the secant of latitude. Consequently, the input latitude bounds must be less than +90 and greater than -90 degrees.

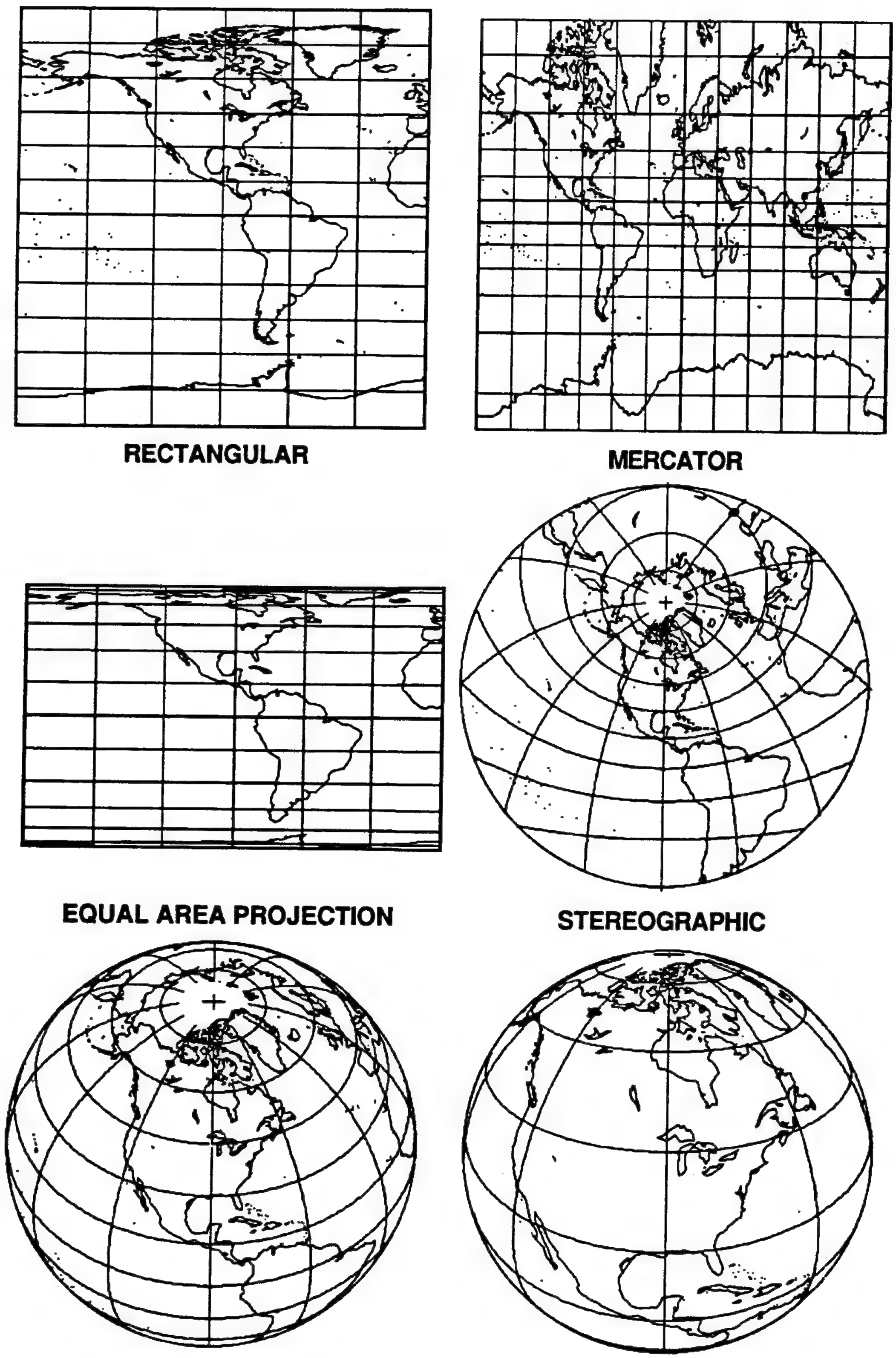

Figure 7-30. Sample Views of Available OATS Map Projections

- *Equal Area* - This is the third of OATS' cylindrical map projections, and is also known as the Lambert Cylindrical Equal-Area projection. It preserves area size of map features by making a perspective projection of the Earth sphere onto the encircling projection-cylinder using the sine of the latitude. It's major drawback is that there is extreme shape and scale distortion close to the poles. Latitude bounds should not exceed -90 or +90 degrees.
- *Stereographic* - This map projection presents a view of the sphere projected onto a plane tangent to (one point touching) the sphere. It presents a view of exactly half of the sphere, and requires input of the latitude and longitude of the point of tangency. This projection preserves the shape of map features (conformal) and relative directions at any given point (azimuthal). Its major drawbacks are the area and scale distortions near the edges.
- *Orthographic* - The orthographic map projection is equivalent to a perspective projection viewed from an infinite distance. Zero distortion exists only at the center, with significant distortion near the edge of the hemisphere that is visible. This projection is useful because it resembles the earth from a perspective view while maximizing the visible surface. It provides a very reasonable approximation to a three-dimensional view of the sphere and can be used effectively for showing the space track of a satellite. OATS requires the latitude and longitude of the center point of the view (actually the tangent point of the projection plane). A *Scale* factor is also required to determine the size of the spherical plot. A scale of 1.0 will cause the orthographic projection to fill the available plot window. Values smaller than 1.0 are usually used to allow room to plot space tracks; however, values greater than 1.0 are acceptable.
- *Vertical Perspective* - This map projection mimics the view of the Earth as seen from a nadir pointing satellite in orbit. Distortion is minimized at the center only, and grows as the edge is approached. It is possible with the radio buttons provided to select whether the viewing point comes from *Fixed Values* of *Latitude*, *Longitude*, and *Altitude* provided by the user in Figure 7-29, or from a *Satellite Ephemeris*. In either case, a *Scale* factor is required similar to that used for the orthographic projection. If *Satellite Ephemeris* is selected, and if one or more ephemeris files have been opened (see Section 9.1), then an additional dialog as shown in Figure 7-31 will be displayed when the Map Projection dialog is exited.

This dialog allows the view point to be selected as any point in any of the open ephemeris files. Double clicking on any file name from the *Ephemeris File List* will show that file as the *Active File*, show the *Time Span* available, and place the start time of the ephemeris file into the *Year*, *Month*, *Day*, *Hour*, *Minute*, and *Secs* fields of the *Time* display. The *Latitude*, *Longitude*, and *Altitude* of the satellite at that time will also be displayed. Any new time within *Time Span* can be manually entered into the *Time* parameters. The *SHOW Position*

button can be used to find out the satellite position at the newly entered time. Either *OK* or *Cancel* from this dialog will exit to the main menu.

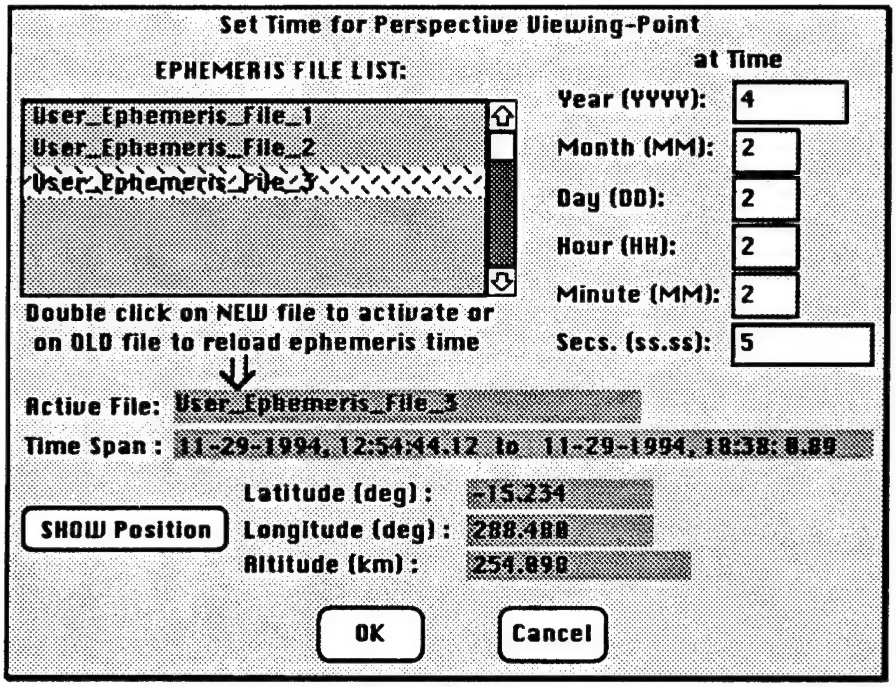

Figure 7-31. Dialog for Ephemeris-Derived Perspective View Point

Options

This command presents the dialog shown in Figure 7-32 which allows the user to select the optional details defining a plotted map. The *Map Source* radio buttons allow selection of the data which is used to plot the map boundary lines. Both the *High Resolution* and *Low Resolution* sources will draw on self-contained databases of latitude/longitude pairs that define the coastlines of land masses. The principal difference between these two sources is that a low resolution plot will execute faster, but will omit many small islands and delete some details from continental coastlines. A *User-Supplied Map File* can also be used as the source of plot data. The format for such a file is discussed in Section 10.5. A checkbox is provided to turn on or off the *Lat/Lon Coordinate Grid*, with parameter inputs provided to set the *Latitude Grid Width.* and *Longitude Grid Width.* Because no labeling of grid coordinate lines is provided, the checkbox to *Highlight Lat/Lon Zero-Pt Lines* can be useful for identifying the Equator and the Prime Meridian. *Map Appearance* allows a choice of a *World-View Map*, where green land masses are displayed on blue ocean background, or of a *Continental Outline Map*, where borders of land masses are plotted on a uniformly colored background, or of a *World-View + Outline* combination of the two which highlights the outlines of the solid green land masses. The *Horizontal* and *Vertical Map Margins* can be set as pixel parameters to allow a pre-defined minimum white space around a plotted map.

This white space is helpful when cutting and pasting OATS-generated pictures to other applications (see Appendix B). The *Geographic Outline Line Thickness* and the *Coordinate Line Thickness* can be set using one of the radio buttons provided. These will change the thickness of the lines defining the land outlines and the coordinate grid. Thicknesses range from a *Normal* single-pixel width line to *Jumbo* which has a line width of 4 pixels. A checkbox is provided to plot an *Outline Border for Map* which is the same thickness as that selected for the *Coordinate Line Thickness*. All parameters set from this dialog are preserved between executions of OATS. The *Cancel* button will return to the main menu without recording any of the parameter changes made in this dialog, while *OK* will set all map option parameters as shown in the dialog.

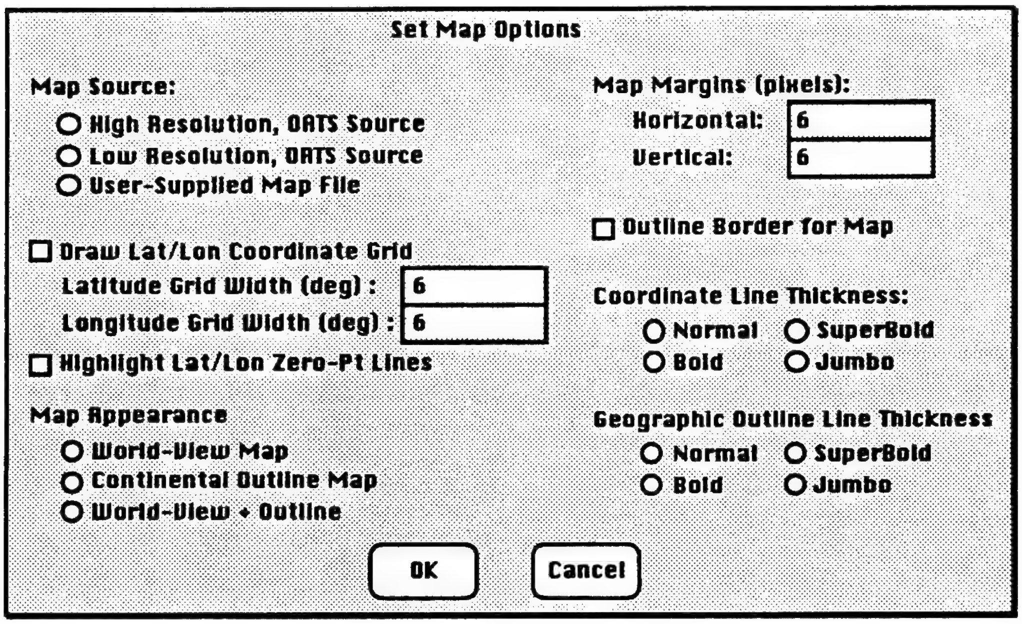

Figure 7-32. Map Options Dialog

Colors

This menu selection presents the third level of menu options shown in Figure 7-33 which allows the user to individually select the colors used for **Geographic** (land mass) lines, **Coordinate** lines, **Background** shading for continental outline maps, and for the **Map Border**. All of these color-related selections will bring up the Color Selection utility dialog discussed in Section 3.5 and shown in Figure 3-5.

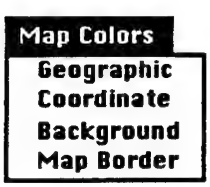

Figure 7-33. **Map Colors** Sub-Menu

Standard Maps

This menu selection presents the third level of menu options shown in Figure 7-34. The use of standard maps provides a mechanism to **Save** and **Retrieve** frequently used background maps. While the process of just plotting a map is fairly brief, the entire process of deciding on projection, colors, and options can be very repetitive and time-consuming for some analyses. Retrieval of a background map which has been previously plotted and fine-tuned saves time. If necessary, features like ground stations or targets or even an orbital plot can be saved as part of a standard map; however, they cannot be changed or removed once saved with a standard map. When a **Retrieve** is done, all crucial parameters defining a map projection are also retrieved and read into OATS. The **Save** command brings up the dialog shown in Figure 7-35, requesting a name for the standard map file to be saved. OK will save the map in the Graphics Window to the current directory, while Cancel will return to the main menu. A standard map can be imported into a marquee in the Graphics Window that is a different size than that used to create it (see Section 4.5); however, standard maps shrink well and expand poorly. As a rule, when creating a standard map they should be constructed at the maximum reasonable window size and using a 1-by-1 page setting (see Figure 5-14).

Figure 7-34. **Standard Maps** Sub-Menu

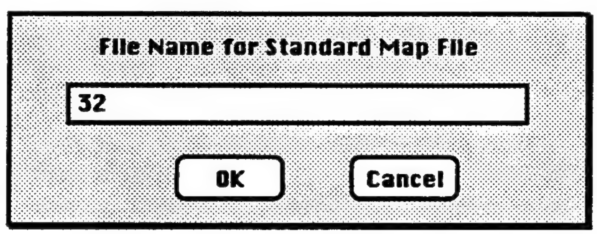

Figure 7-35. Dialog to Identify Standard Map File Name

Note that the **Save** or **Open** menu selections done from the **File** menu (see Section 5.2) perform a function similar to the standard map commands; however, one critical difference is that the parameters defining the map projection are not propagated into or taken from the saved plot file.

Plot Map

This menu selection will initiate execution of a map plot as defined by the dialogs in the previous discussion of set-up procedures for maps. This command can also be initiated with the command-key **⌘-M**. With one exception, the **Plot Map** command will immediately commence to plot your map in the Graphics Window, regardless of whether the window is visible or if it is the active

window. The exception comes when the user has specified that an external file will be used to define the map (see Figure 7-32). In this instance, the notice shown in Figure 7-36 will appear. After clicking on this notice, the Macintosh standard file interface dialog will be displayed and allow the user to select the map file.

Figure 7-36. Map File Identification Notice

7.4 MISCELLANEOUS PLOTTING COMMANDS

The miscellaneous plotting commands appear with the **Map** function at the bottom of the **Plot** menu (see Figure 7-1). They do not specifically produce plotted information, but are designed as general purpose commands that enhance or modify plots.

7.4.1 ZOOM PROCESSES

Zoom will bring up the sub-menu shown in Figure 7-37. This set of commands will change the display size of plotted data. Note especially that the zoom processes do NOT change the resolution of plotted data, nor do they change the size of the Graphics Window. They just make the image easier to see by making it larger or more compact. For example, an image at extreme magnification will start to show individual pixels in the plot--it will not show more details. Zoom is not a substitute for a more focused plot area. If what the user seeks is a "better" plot with clearer detail, it will be necessary to manipulate the scale or plot parameter limits to confine the area of interest prior to executing a plot.

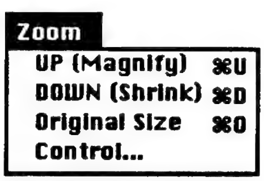

Figure 7-37. **Zoom** Menu

The **UP** menu selection causes the plot display to be magnified, and can be accessed with the **⌘-U** command key. In response to this magnify command, the cursor will be replaced by a locator icon (see Section 7.4.2). The user then positions this cross-hair over the center of the area of the display that is to be enlarged, and clicks the mouse button to initiate a zoom. The **DOWN** menu selection causes the plot display to shrink, and can be accessed with the **⌘-D** command key. Either of these commands requires that plotted data lie in a single layer. If this is not the case, multiple layers will be added together before zooming. **Original Size** will return the plot display to the original size, and is also available through the

⌘-0 command key. **Control** brings up the dialog shown in Figure 7-38 which allows the user to change the amount of magnification or reduction via a standard Macintosh control slide. At maximum value, the image can be shown as 10 times its original plot size or at 10 percent of its original size. The power can be changed in increments of $^1/_4$ power.

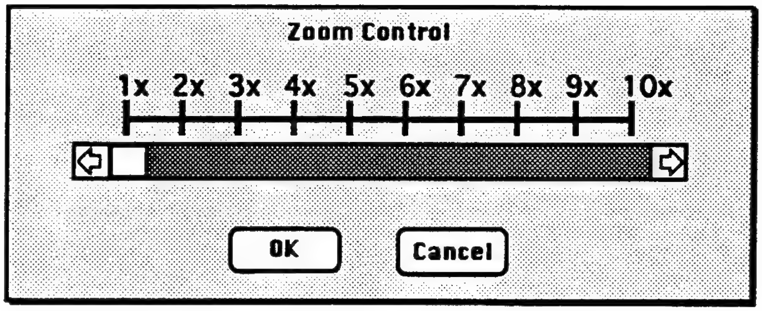

Figure 7-38. Zoom Control Dialog

7.4.2 SYMBOLS AND COLORS

As discussed throughout Section 7, all individual plot processes have individual controls that can be used to change the size of plotted icons, the colors of plotted lines, and the colors of shaded regions. The **Symbols & Colors** menu selection displays the dialog shown in Figure 7-39. It provides the user a master control dialog that can be used to set the size of all plotting icons and all program colors. More importantly, it provides the user with a summary display of many of the critical plotting variables, making it easier to compare them. Note that it also shows pictures of all the icons.

All plot objects are shown in the upper portion of this dialog organized loosely according to function. Color swatches are indicated by the small rectangular cross-hatched areas in the figure; however, these are not displayed when the dialog is first opened. Colors can be displayed with the *SHOW Plot Colors* button. Individual colors can be changed using the small buttons located between the name of each plot object and its color swatches. Color buttons are labeled according to the numerical ordering of the 10 basic plot functions, as described at the beginning of Section 7. Where appropriate, *L* or *S* has been added to indicate line color buttons or shading color buttons. Because map characteristics do not fit into the basic functions numbering scheme, these buttons have been assigned an appropriate two-letter abbreviation. Selecting one of the color buttons will bring up the Color Selection utility dialog discussed in Section 3.5 and shown in Figure 3-5.

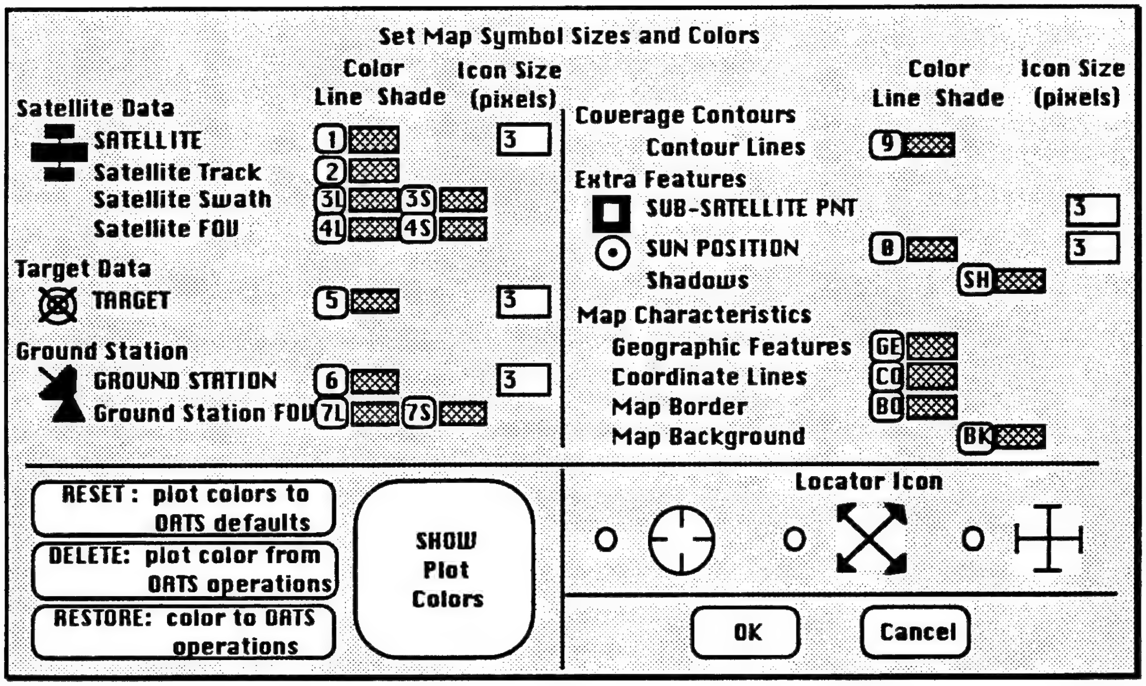

Figure 7-39. Master Dialog for Symbol Sizes and Colors

The bottom right portion of the dialog in Figure 7-39 contains a set of radio buttons to allow the user to select a *Locator Icon*. This icon is used as a cross-hair in place of the cursor for zoom magnification (see Section 7.4.1) and in Locator Mode (see Section 7.4.3). The bottom left portion contains a set of buttons that permit modification of all OATS color settings. The *RESET* button will change all colors to default values. While there is no set of colors that can be fixed that will satisfy all of the possible uses of OATS, a general purpose default group of colors is saved internally that is internally consistent with a majority of OATS functions. The *DELETE* button will set the computer's color palette (the list from which plot colors are assigned) to a gray scale, and assign black, gray, or white to all plot colors. Correspondingly, the *RESTORE* will return the computer to a color palette; however, plot colors will not automatically be restored. They can be changed individually or en masse using the *RESET*. The *OK* button will save all settings made from this dialog and exit to the main menu, while *Cancel* will save no changes and exit to the main menu.

7.4.3 LOCATOR MODE

Locator Mode enters OATS into a mode where the latitude and longitude of a point on a plot indicated by the cursor is interactively computed and displayed. This mode can be accessed from the **Plot** menu or with an **⌘-L** command key. When **Locator Mode** is issued, the cursor changes to the locator icon specified by the settings shown in Figure 7-39. All locator icons are types of cross-hairs to allow the user

to identify map locations with single-pixel resolution. A selection of three is available. The latitude and longitude are displayed in the title bar of the Graphics Window. If the cursor is pointing outside of the defined boundaries of the map or plot display, the coordinate fields will show "?????" to indicate no coordinate available. If no plot has been made, then coordinates will not be defined anywhere within the Graphics Window. Locator mode works for all map projections. To exit Locator Mode, simply move the cursor to a location outside the Graphics Window such as into the menu bar at the top of the computer screen. The cursor will be returned to the normal pointer arrow and OATS will return to the main menu.

7.4.4 WIPE SCREEN

Wipe Screen eliminates all layers of plotted data, thereby clearing the Graphics Window. This command is used to start a fresh plot. It can also be accessed with an **⌘-W** command key.

SECTION 8 - COVERAGE MENU

The OATS program has the ability to perform three types of orbit coverage analysis--tabular coverage, graphical coverage, and look angle coverage. These three computational options are accessed by the **Coverage** menu, shown in Figure 8-1. Each of the types of coverage analysis, **Tabular**, **Graphical**, and **GS Look Angles**, has a sub-menu that offers several choices used to set-up the computational run. After setting the parameters, the specific Run option is used to initiate execution of the coverage computation.

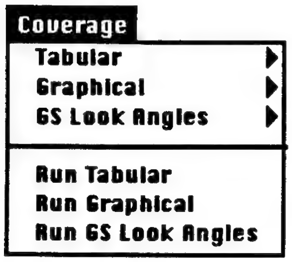

Figure 8-1. **Coverage** Menu

8.1 TABULAR COVERAGE

This analytical procedure yields a tabulated list of visibility statistics for a user-defined combination of ground stations, satellites, and targets. Up to 20 ground stations, 27 satellites (synonymous with a maximum 27 separate active ephemeris files), and 100 targets may be used in a single run. The **Tabular** coverage function computes orbital coverage statistics for a system of satellites as viewed by a set of ground targets. A target is said to be covered when one or more of the satellites in the system is visible to the target. Any or all of the satellites may optionally have a constraint applied such that at least one ground station must be visible for coverage to exist. This is a condition that would apply if a direct satellite communications link is required. The antenna pattern is specified for each satellite individually. The **Tabular** coverage function uses an oblate Earth and can optionally account for atmospheric refraction effects.

8.1.1 PREPARATION MENUS

In order to execute a tabular coverage run, four sets of data must be selected. These include at least one ephemeris file, antenna parameters for each file, optional ground stations, and at least one target position. Ephemeris files are selected first using the **Ephemeris** menu (see Section 9.1) to select and open an active list of files. All open ephemeris files will be used for the tabular coverage run. The remaining sets of data are set using the preparatory sub-menus shown in Figure 8-2.

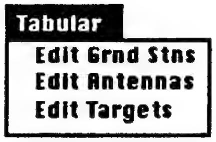

Figure 8-2. **Tabular** Coverage Sub-Menu

Edit Grnd Stns

This menu selection allows the user to choose the set of ground stations that will be used for the tabular coverage run. It brings up a dialog identical to that shown in Figure 7-16. The function of that dialog is discussed in Section 7 and the user is referred there for information on how to fill the active list of ground stations. At least one ground station is required if any of the ephemeris files is associated with a ground station constraint (see below).

Edit Antennas

When each ephemeris file is opened, it is assigned a default set of antenna parameters. These parameters can be changed using the **Edit Antennas** menu, which brings up the dialog shown in Figure 8-3. To change the antenna parameters, select an ephemeris file from the active list (see above) by double clicking on the name of a file in the *Ephemeris File List*. The information for that file will be displayed in the parameter boxes. The name of the selected file will appear in the *Ephemeris File* box to verify the file that is in the process of being changed. The type of antenna

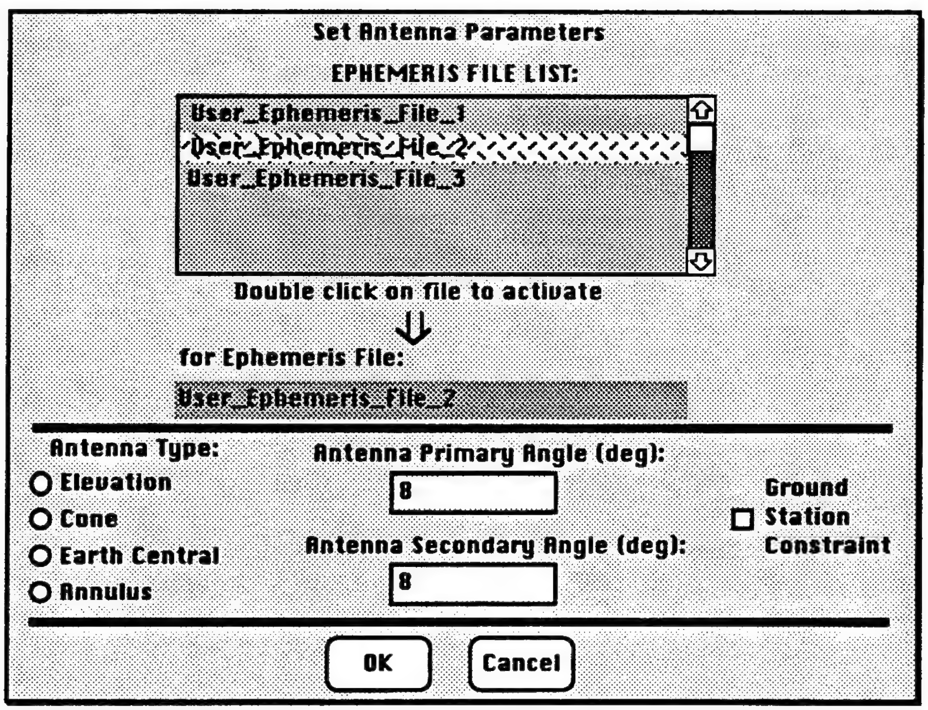

Figure 8-3. Antenna Parameters Dialog

will be displayed along with the antenna angle parameter for that antenna type. The antenna pattern may be defined by an earth central angle, a cone angle, an elevation angle, or as an annulus. The geometrical definition of these angles is provided in Appendix A. The secondary angle is applicable and activated only for the case of an annular antenna pattern. A ground station flag may be set for the selected ephemeris file. If the flag is activated, the satellite must be in view of the target and the ground station at the same time for the coverage event to be added to the statistics. These parameters can be set for each of the ephemeris files in the *Ephemeris File List*. The *Cancel* button will return all antenna settings to their values before entering the dialog.

Edit Targets

This menu selection allows the user to choose the set of targets that will be used as part of the tabular coverage run. It brings up a dialog identical to that shown in Figure 7-13. The function of that dialog is discussed in Section 7 and the user is referred there for information on how to fill the active list of targets.

8.1.2 **RUN TABULAR** MENU

When all parameters have been set, a tabular coverage run is initiated by selecting **Run Tabular** from the **Coverage** menu shown in Figure 8-1. The Tabular Coverage Dialog shown in Figure 8-4 will appear. The initial *Start Time* and *Stop Time* will be the minimum and maximum values found in the collected set of ephemeris files. These can be changed, but must be within the bounds of all files used. The step size will be used to set the output computational interval. There is no direct relationship between this interval and the intervals used when creating ephemeris files. An interpolation routine is used to compute satellite state vectors from the available ephemeris data. A checkbox exists in the dialog to allow the option to *Print Up/Down Times* for each coverage period to the output tabular data. A checkbox also exists to allow the *Atmospheric Refractive Correction* to be turned on or off. *Cancel* will return the user to the main menu, while *OK* will initiate calculation of the tabular coverage. The Macintosh standard file interface will first appear to allow the user to select a file and directory for output of the computed tabular data. The Tabular Window will contain an echo of the computed output tabular data. This window may be opened from the **Window** menu (see Section 5) after completion of calculations, or before **Run Tabular** is selected if the user wishes to watch the calculations in progress. A tabular coverage run may be aborted by the user by pushing and holding the mouse button. Execution will stop, there will be no alert message and whatever portion of the file of computed tabular data has been generated will be left intact. An example of the output file of tabulated coverage data is shown in Section 11.

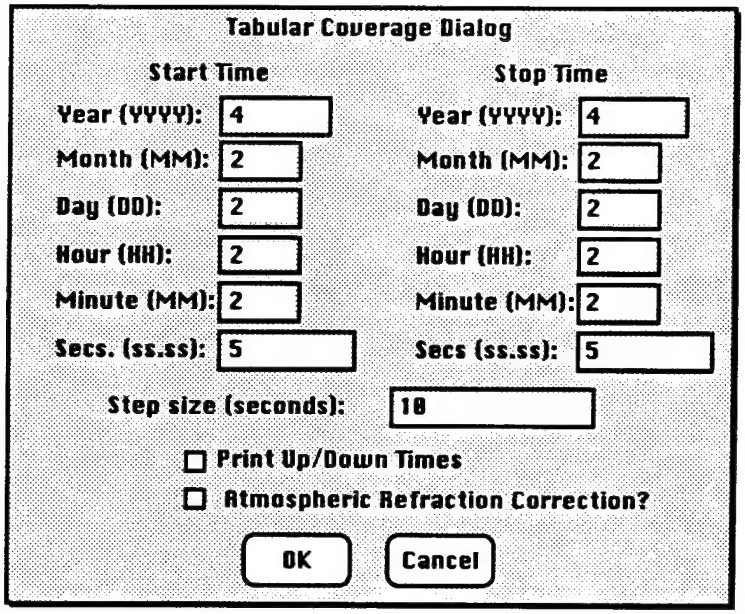

Figure 8-4. Tabular Coverage Dialog

8.2 GRAPHICAL COVERAGE

The graphical coverage function computes world-wide coverage of a system of satellites. It uses the meridian mesh technique of Casten and Gross (Reference 7) to compute the cumulative coverage, average outage, and maximum outage times over a global grid uniformly spaced in latitude and longitude. Coverage statistics are computed at each point in the grid. The technique is quick because a spherical earth is used as a simplifying assumption for the target positions, although an oblate earth model is used for the ground station positions. Coverage is calculated using geometry only--no atmospheric or aberration effects are included in the model.

This analysis function does not produce coverage information that is of direct value to most users. Rather, it serves as a set-up procedure that yields a single file of tabulated coverage data that can be employed by the **Plot** menu options (see Section 7) to produce a graphic contour or density mapping of satellite coverage. This mapping is usually shown superimposed on an earth plot to show the extent of coverage for a given satellite grouping. Both dimensions of the global latitude/longitude mesh size can be specified by the user. An increment as small as 1.0 degree can be used; however, the smaller the mesh the longer the compute time. The mesh effectively takes the place of the individual targets used in the tabular coverage procedures discussed above. Exactly as with tabular coverage, any or all of the satellites may optionally have a constraint applied such that at least one ground station must be visible for coverage to exist. Again, up to 20 ground stations and 27 satellite ephemeris files may also be used as simultaneous inputs to the graphical coverage analysis.

8.2.1 PREPARATION MENUS

In order to execute a graphical coverage run, four sets of data must be selected. These include at least one ephemeris file, antenna parameters for each file, at least one ground station, and the latitude and longitude spacing of the global mesh elements. Ephemeris files are selected first using the **Ephemeris** menu (see Section 9.1) to select and open an active list of files. The remaining sets of data are set using the preparatory sub-menus shown in Figure 8-5.

Figure 8-5. **Graphical** Coverage Sub-Menu

Edit Grnd Stns

This menu selection allows the user to choose the set of ground stations that will be processed as part of the tabular coverage run. It brings up a dialog identical to that shown in Figure 7-16. The function of that dialog is discussed in Section 7 and the user is referred there for information on how to fill the active list of ground stations.

Edit Antennas

This menu selection allows the user to choose the antenna parameters that define the visibility pattern for each satellite. It brings up a dialog identical to that shown in Figure 8-3. The function of that dialog is discussed in Section 8.1.1 and the user is referred there for information on how to set the antenna parameters.

Edit Mesh

This menu selection allows the user to set the latitude and longitude spacing of the global mesh elements. It brings up the dialog shown in Figure 8-6. Mesh dimensions must be entered as integer values greater than or equal to 1 degree. The mesh need not be "square" (i.e. equal valued).

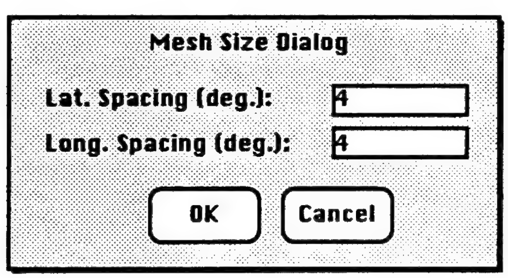

Figure 8-6. Mesh Size Dialog

8.2.2 **RUN GRAPHICAL** MENU

When all parameters have been set, a graphical coverage run is initiated by selecting **Run Graphical** from the **Coverage** menu shown in Figure 8-1. The Graphical Coverage Dialog shown in Figure 8-7 will appear. The initial *Start Time* and *Stop Time* will be the minimum and maximum values found in the collected set of ephemeris files. The step size is used to set the computational interval. Again, there is no direct relationship between this interval and the intervals used when compiling the ephemeris files. A checkbox exists in the dialog to allow the option to turn *Data Compression* of the output file on or off. A discussion of compression and of how the data in the output file is mapped onto the global grid is provided in Section 10.7. *Cancel* will return the user to the main menu, while *OK* will initiate calculation of the file required to make coverage plots. The Macintosh standard file interface will first appear to allow the user to select a file and directory for output of the computed data. If the user decides to terminate generation of the coverage run, the mouse button can be pressed and held. An alert message notifying the user of the aborted run will be displayed, and any portion of the generated file will be deleted. If the user has elected to have a progress display (see **System Params** under Section 5.1), a graphic will be presented showing the file name, a tabular value of percentage of file completed, and a fill-bar graphic showing progress toward completion. This graphic can be valuable in cases where a very small mesh and/or large ephemeris intervals result in lengthy wait periods. If the user suspects there is a problem with the initial conditions, the file generation process can be aborted. Note that the whole of the procedure involved in generating a graphical coverage file is not linear, and that the percentage complete shown by the status display is only an approximation.

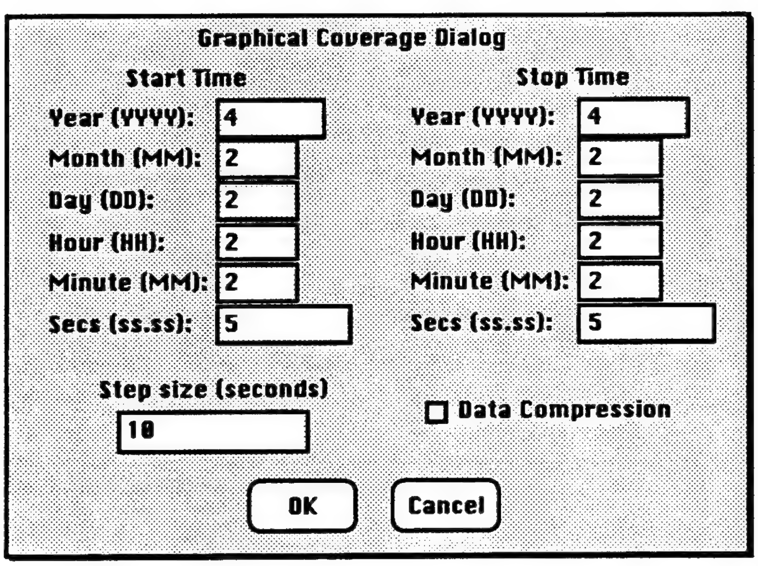

Figure 8-7. Graphical Coverage Dialog

8.3 LOOK ANGLE COVERAGE

Look Angle coverage is used to produce a tabular list of data that describe where and when a single ground station will be able to view a single satellite as it passes overhead. The listing includes readouts of time vs. azimuth, elevation, range, range rate information, shadow status, and signal attenuation. Calculations for the look angles solutions use an oblate earth, atmospheric refraction, aberration, and a Hopfield propagation delay model.

8.3.1 PREPARATION MENUS

In order to execute a look angles coverage run, three inputs must be selected. These include a single ground station, a single satellite ephemeris, and the up-link and down-link communication frequencies. At least one ephemeris file must first be selected and opened using the **Ephemeris** menu (see Section 9.1). The remaining data selections are performed using the preparatory sub-menus shown in Figure 8-8.

GS Look Angles
- **Select GS**
- **Select Eph. File**
- **Set Frequencies**

Figure 8-8. **GS Look Angles** Coverage Sub-Menu

Select GS

This menu selection allows the user to choose the ground station that will be used for the look angles coverage run. It brings up the dialog shown in Figure 8-9. A ground station is selected from the *Cataloged Ground Station List*, which is maintained between executions of OATS. This is the same cataloged list used in the **Plot** menu (see Section 7) as a source of ground stations for plotting. To select and activate the one required ground station from the list, double click on the ground station name. The station information (name, latitude, longitude, altitude, and elevation mask) will appear in the *DISPLAY* information boxes. The cataloged list can be edited using the *Clear* button to erase all entries or the *Delete* button to delete an entry that the user has highlighted with a single mouse click. Entries can be added by manually typing data into each of five *New DataEntry* boxes and clicking the *Add* button. A new cataloged list can also be retrieved from a previously saved file of ground stations (see Section 7) using the *RETRIEVE from File* button. A mouse click here will bring up the standard Macintosh file interface, which can be used to locate and select a file of ground stations. *Cancel* will as usual return the cataloged list and the active ground station to their status before the dialog was entered.

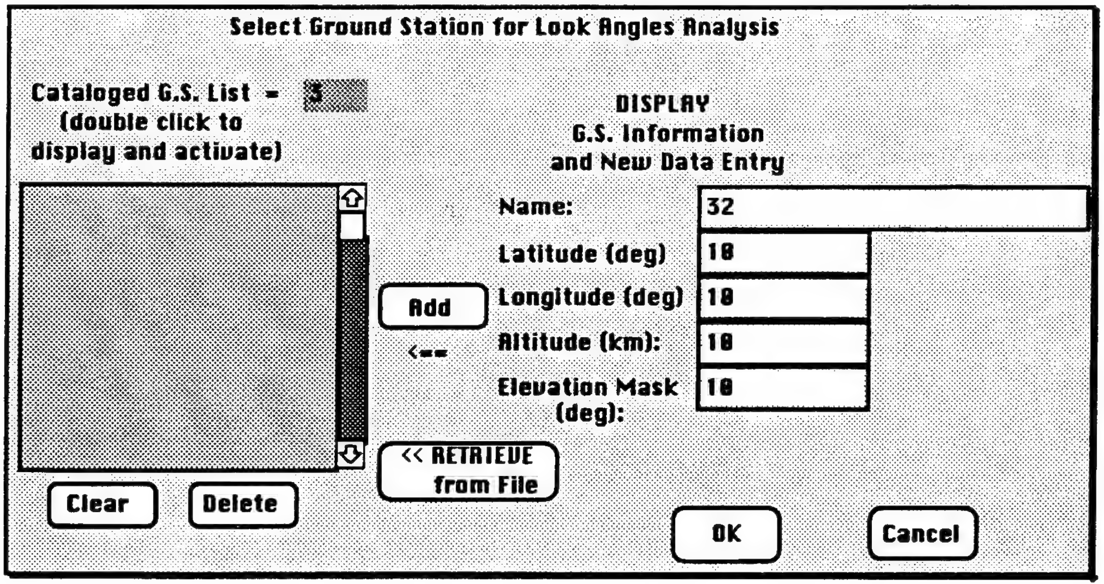

Figure 8-9. Look Angles Ground Station Selection Dialog

Select Eph. File

This menu selection allows the user to choose the satellite ephemeris file to be used for look angle processing. It brings up the dialog shown in Figure 8-10. If no files appear in the list, no files are open and the user must visit the **Ephemeris** menu (see Section 9.1). To designate the file you want to use for a look angles run, highlight the file name with a mouse click and exit with *OK*.

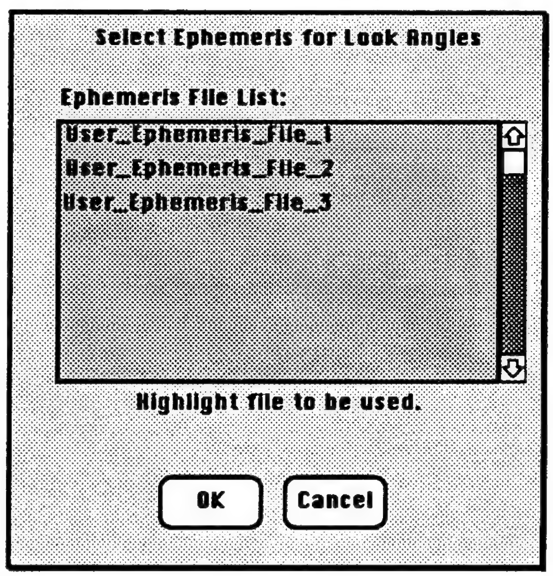

Figure 8-10. Look Angles Ephemeris File Dialog

Set Frequencies

Figure 8-11 shows the menu which appears after this menu selection. It allows the user to choose the up-link and down-link frequencies (in megahertz) used to compute signal attenuation. A switch is also available to turn this computation on or off, which will shorten the computation time and the printout format. The mathematical formulation of the link margin computations can be found in Reference 8.

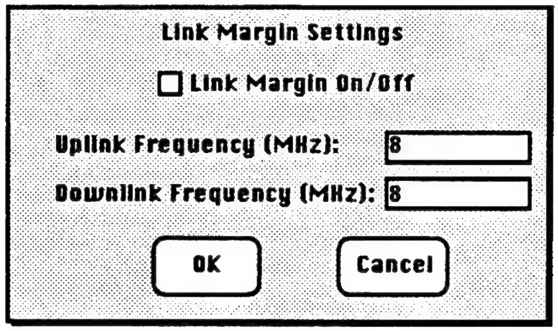

Figure 8-11. Link Margin Settings Dialog

8.3.2 **RUN GS LOOK ANGLES** MENU

When all parameters have been set, a look angles coverage run is initiated by selecting **Run GS Look Angles** from the **Coverage** menu shown in Figure 8-1. The Look Angles Run Parameters Dialog shown in Figure 8-12 will appear. The initial *Start Time* and *Stop Time* will be the minimum and maximum values found in the chosen ephemeris file. These may be modified, but the coverage interval must be within the bounds of the file. The full interval of this file is shown in the *File Time Span* field in case the user requires adjustments. If the *Start Time* or *Stop Time* is adjusted, be sure the new times still fall within the times in the selected ephemeris file. The step size will be used to set the computational interval. Again, there is no direct relationship between this interval and the interval used when creating the ephemeris file. Checkboxes exist in the dialog to allow the option to turn *Hopfield Propagation Correction* and *Atmospheric Refraction Correction* on or off. *Cancel* will return the user to the main menu, while *OK* will initiate calculation of look angle coverage. The Macintosh standard file interface will first appear to allow the user to select a file and directory for output of the computed look angles data. The Tabular Window will contain an echo of the computed output look angles data. This window may be opened from the **Window** menu (see Section 5) after completion of calculations, or before **Run GS Look Angles** is selected if the user wishes to watch the calculations in progress. A look angles coverage run may be aborted by the user by pushing and holding the mouse button. Execution will stop, there will be no alert message and whatever portion of the file of computed look angles data has been generated will be left intact. An example of the output file of look angles coverage data is shown in Section 11.

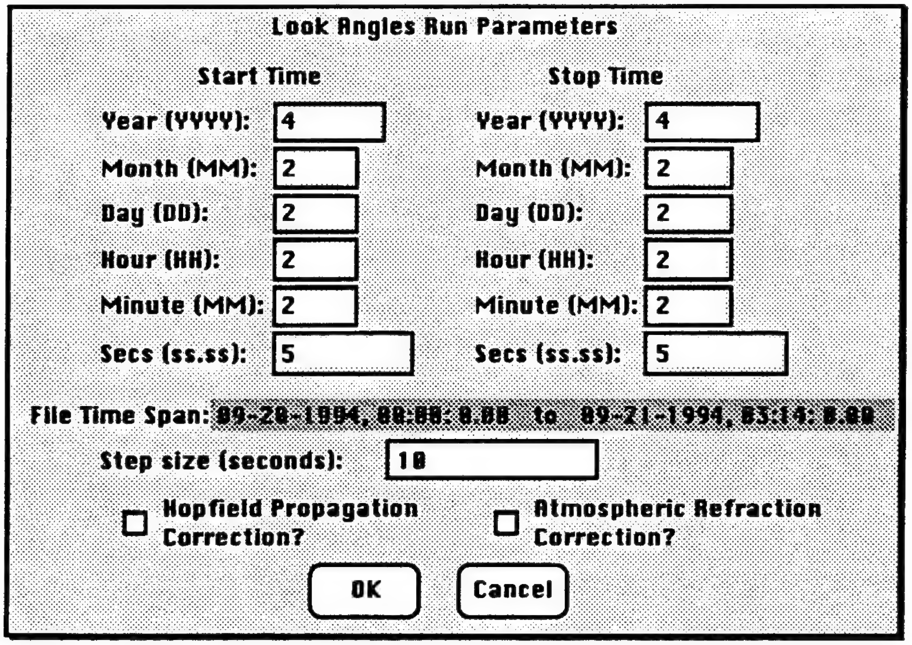

Figure 8-12. Look Angles Dialog

SECTION 9 - EPHEMERIS MENU

One of the cornerstones of operating OATS involves the use of ephemeris files. The **Ephemeris** menu provides an interface that allows the user to open files for plotting and coverage analysis activities and to inspect files prior to opening them for analysis. Choosing the **Ephemeris** menu produces the sub-menu shown in Figure 9-1, which allows the user to **Inspect Files** or to **Open Files**.

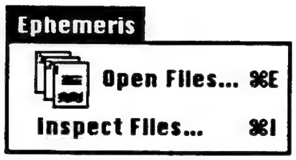

Figure 9-1. **Ephemeris** Menu

9.1 OPEN FILES

OATS operates with two lists of ephemeris files. This is reflected in Figure 9-2, which shows the dialog produced by selection of **Open Files**. The *Available Files* list on the left is composed of files identified by the user which are of potential interest during this execution of OATS. In the vernacular of the program, these are referred to as "cataloged files". OATS retains knowledge of the location of these files for the duration of the current program execution, although none of them are formally opened. There is no specified limit to the number of files that can exist in this list; however, as files are entered one at a time, an effective limit is defined by the user's need and persistence. The other list of *Files to be Opened* holds the

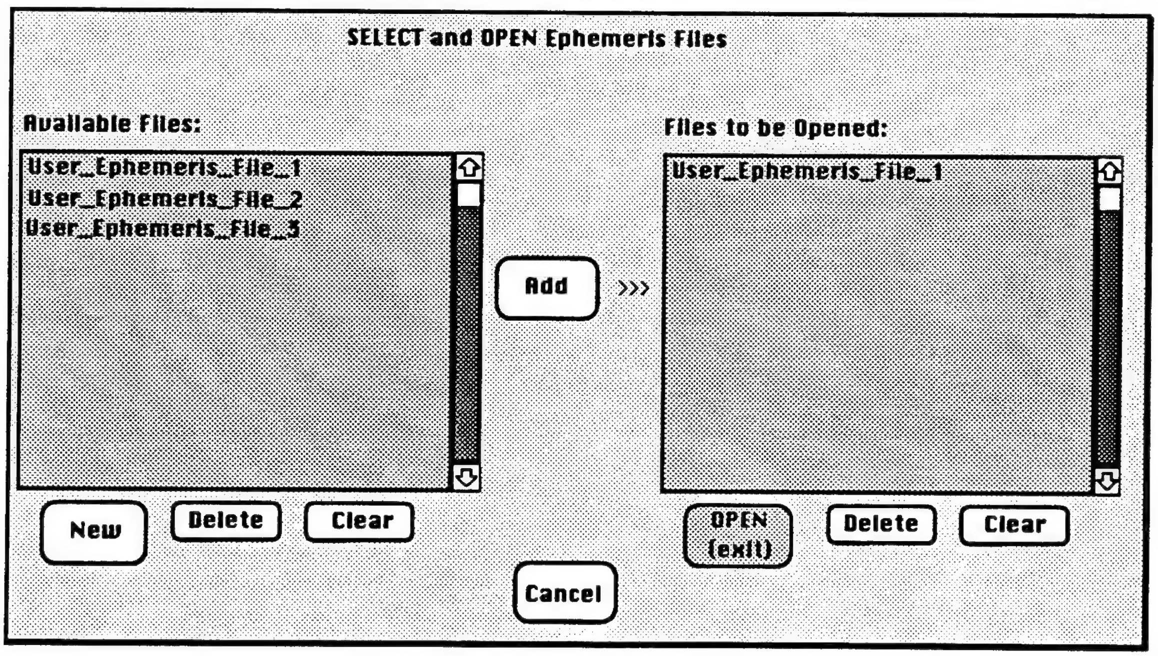

Figure 9-2. Open Ephemeris Files Dialog

"active files". These files are formally opened upon termination of this dialog via the *Open* button. This active list can contain up to 27 files, and is made available to the user at numerous dialogs throughout the **Plot** and **Coverage** menu systems. File location information for both lists is lost upon program termination. If the user temporarily switches out of OATS to some other program (e.g. Finder) and executes a command that affects the location of an identified file (e.g. move it to another directory), OATS will not notice there is a problem until you attempt to *Open* the active files list. Likewise, files which do not have an ephemeris format can be manipulated and selected with this interface dialog without notice of the problem until an *Open* is attempted

Both lists in Figure 9-2 have their respective *Clear* button, which removes all files from that list. Both lists also have their respective *Delete* button which will delete a single file entry which has been highlighted with a mouse click. *Cancel* will exit the dialog and return both lists to their states prior to entry to the **Open Files** dialog. The *New* button is the default control button for this dialog. Clicking *New* will bring up the Macintosh standard file interface, which permits the user to select a file located in any directory. From the standard interface, clicking *SELECT* will add the highlighted file to both the cataloged and active lists. If a single file is highlighted by a mouse click in the cataloged list then the *Add* button will copy that file's data into the active list, but *Add* will do nothing if the file is not highlighted. As noted in Section 6, there is another way for files to be entered onto the active list. New ephemeris files generated by OATS are automatically entered onto the active list and opened.

Normal use of the **Open Files** dialog interface involves repetitive use of the *New*, *Delete*, *Clear*, and *Add* functions until the desired list of files is achieved in the active list, whereupon the *Open* button is used to exit the dialog, open the files, and access the defining limits of the selected files. Ephemeris files can be imported from other applications, used by OATS, and activated via this interface provided they adhere to certain formatting restrictions. File format is reviewed in Section 10.2. The user will note that files generated by OATS are processed more quickly through this interface because they have header data containing the file's limits. **Open Files** can also be selected by using the **⌘-E** command-key.

9.2 <u>INSPECT FILES</u>

The **Inspect Files** menu option is designed to allow the user to preview ephemeris file data prior to including it in the cataloged or active lists. Selection of **Inspect Files** from the menu or using the **⌘-I** command-key will bring up the dialog seen in Figure 9-3, but with all file descriptive fields empty. The *SELECT File* button activates the Macintosh standard file interface, which allows the user to select a file for preview from any directory. Any file thus selected will have its name displayed under *File Name*. If a

file has been generated by OATS, it will possess header information that summarizes the file contents (see Section 10.2). All informational data fields shown in Figure 9-3 will then be displayed. If the file is not an OATS standard format file, then a warning will be generated and the only valid information will again be the *File Name*. After a file is selected, the *View Orbital Elements* button will display a dialog similar to those seen in Figures 6-4 through 6-9 that are used to display orbital element data. It will be possible to use the *Save As* option in those dialogs to save the orbital elements data to a file if desired. If the file is not OATS standard format, a warning message will be issued.

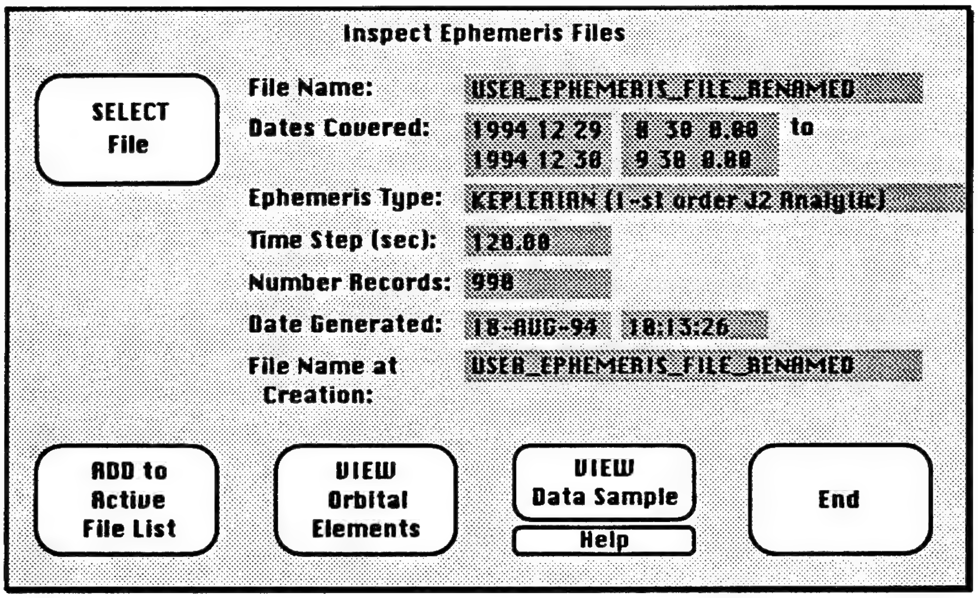

Figure 9-3. Inspect Ephemeris Files Dialog

Whether or not the file is OATS standard, the *View Data Sample* button can be used to directly preview the data. OATS standard ephemeris file format employs ASCII character data so that the files can be viewed. Header data will not be shown in the preview. *View Data Sample* activates the Utility Text Entry window (see Section 3), displays the file data, and deactivates the mouse. Data is displayed with line numbers, followed by the characters "##" to distinguish the numbers from the file data. Motion through the file and a return to the program are possible using selected keys from the keyboard. A review of the keys is shown in Figure 9-4. This dialog also allows the user to set the number of lines of ephemeris data that will be shown in the preview window. If it is desired to change the display parameters of the Utility Text Entry window, this can be accomplished through the **Window** menu (see Section 5). The dialog in Figure 9-4 is produced by the *Help* button in Figure 9-3.

The *End* button in the **Inspect Files** dialog returns the user to the main program menu. The *Add to Active File List* will add a file selected for preview to the active files list and open that file. Once added to the list, it is no longer possible to preview the file's data short of returning to the **Open Files** dialog and

deleting the file from the active list. This is due to the fact that only one part of the program may access a file at any given time in the OATS Macintosh environment.

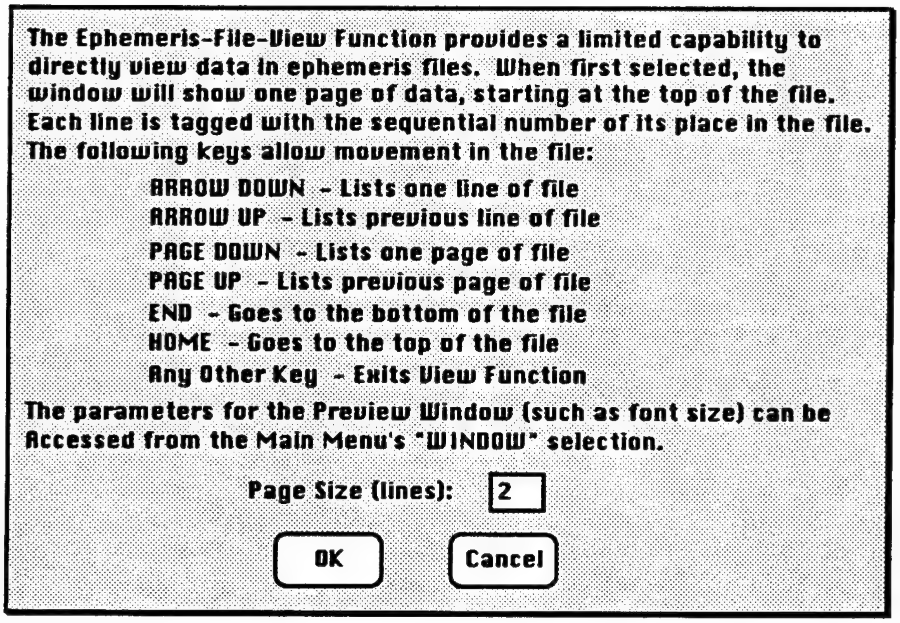

Figure 9-4. Inspect Ephemeris Files Help Dialog

SECTION 10 - FILE FORMATS

This section provides a list and description of all of the files used by OATS with which it is expected the user may wish to directly interact. A number of scratch files are used by the program; however, these are temporary and will never be seen except in the unusual circumstance that there is an abnormal end to program execution that prevents OATS from closing and deleting these files. Unless specifically stated otherwise, all files are ASCII format with sequential access. All can be created using OATS to write the file; however, they may also be created manually from a text editor or by another computer program.

10.1 ORBITAL ELEMENTS

Four different orbit propagation models are used in Version 3.0 of OATS; PPT2 (Brouwer-Lyddane), RUK12 (4^{th} order Runge-Kutta numerical integration), J2 (first order J_2 analytic), and SGP4 (USSPACECOM formulation of Brouwer solution with drag modeling). Each of the four models requires a different input vector file format, with a total of six possible types of input formats for OATS. The RUK12 and J2 input file formats are non-specific and can be defined by any program utilizing such orbital element sets; however, the PPT2 and SGP4 have very specific native formats which are used to store and transmit element sets. The PPT2 orbit model uses NAVSPASUR One-Line Element Sets (OLES) which come in three varieties: PME, Charlie, and Z formats. The SGP4 model uses Two-Line Element Sets (TLES). Any of these six types of orbital element input files may be created by the user with any text editing program, imported from an external source, or created by OATS using the *Save* buttons in the orbital element data entry dialogs (see Section 6.3.2). Figure 10-1 presents a tested functional example of each of the six types of orbital element files, and the following sections discuss the formats individually.

10.1.1 CHARLIE OLES

The Charlie format is valid at 0 hours Zulu. The OLES in Charlie format is 65 characters in length, with the specific native format and the parameters making up the NAVSPASUR Charlie format one-line element set as follows:

```
IIIII.AAAAAAA.MMMMMMM.DDDDD.EEEEEEE.WWWWWWW.NNNNNNN.IIIIIIIYYMMDD
```

where,

IIIII	= satellite SDC number
AAAAAAA	= mean anomaly, fraction of a revolution
MMMMMMM	= mean motion, radians/hergs

DDDDD	= decay, radians/hergs/hergs
EEEEEEE	= eccentricity
WWWWWWW	= argument of perigee, fraction of a revolution
NNNNNNN	= longitude of ascending node, fraction of a revolution
IIIIIII	= angle of inclination, fraction of a revolution
YYMMDD	= year / month / day

10.1.2 Z OLES

The Z format is also valid at 0 hours Zulu. The OLES in Z format is 69 characters in length, with the specific native format and the parameters making up the NAVSPASUR Z format one-line element set as follows:

```
IIIIIRRRRRAAAAAAAAMMMMMMMMDDDDDEEEEEEEEWWWWWWWWNNNNNNNNIIIIIIIIYYMMDD
```

where,

IIIII	= satellite SDC number
RRRRR	= revolution number
AAAAAAAA	= mean anomaly, fraction of a revolution
MMMMMMMM	= mean motion, radians/hergs
DDDDD	= decay, radians/hergs/hergs
EEEEEEEE	= eccentricity
WWWWWWWW	= argument of perigee, fraction of a revolution
NNNNNNNN	= longitude of ascending node, fraction of a revolution
IIIIIIII	= angle of inclination, fraction of a revolution
YYMMDD	= year / month / day

10.1.3 PME OLES

The epoch of the PME format one-line element set is more generalized than the other two OLES formats, because space is allocated to specify the epoch to the nearest ten minutes; however, only the last digit of the year can be specified. This makes the decade during which the OLES is valid ambiguous under some circumstances. The OLES in PME format is 69 characters in length, with the specific native format and the parameters making up the NAVSPASUR PME format one-line element set as follows:

```
IIVRRRRRAAAAAAAAMMMMMMMMDDDDDEEEEEEEEWWWWWWWWNNNNNNNNIIIIIIIIYMMDDHHM
```

where,

II	= satellite SDC number
V	= version number
RRRRR	= revolution number
AAAAAAAA	= mean anomaly, fraction of a revolution
MMMMMMMM	= mean motion, radians/hergs
DDDDD	= decay, radians/hergs/hergs
EEEEEEEE	= eccentricity
WWWWWWWW	= argument of perigee, fraction of a revolution
NNNNNNNN	= longitude of ascending node, fraction of a revolution
IIIIIIII	= angle of inclination, fraction of a revolution
YMMDDHHM	= year / month / day / hours / tens of minutes

10.1.4 TLES

The two-line element set contains two lines, each of which is 69 characters in length. TLES are used for other orbit propagators than SGP4, and have a slightly different format. The specific native format and parameters making up the USSPACECOM TLES format two-line element sets used in OATS are as follows. If a data field is not specifically called out in the explanation, then the TLES must match that field exactly as shown.

```
1 nnnnnU YYLLL  A YYDDD.DDDDDDDD 0.XXXXXXXX  ZZZZZ-J  GGGGG-K T  SSSS
2 nnnnn III.IIII NNN.NNNN EEEEEEE WWW.WWWW AAA.AAAA MM.MMMMMMMM RRRRR
```

where in the first line,

nnnnn	= satellite SDC number
YY	= year of launch
LLL	= launch number of the year
A	= international designator (piece of the launch for multi-payload launches)
YY	= last two digits of epoch year
DDD.DDDDDDDD	= epoch, as day and fractional part of day
0.XXXXXXXX	= first time derivative of the mean motion
ZZZZZ	= second time derivative of the mean motion
J	= exponent of second derivative of mean motion
GGGGG	= drag coefficient for SGP4 theory

`K`	= exponent of drag coefficient
`T`	= ephemeris theory code; "0" is used for SGP4
`SSSS`	= origination code for TLES; this is set to "OATS' if generated by OATS

and where in the second line,

`nnnnn`	= satellite SDC number
`III.IIII`	= inclination (degrees)
`NNN.NNNN`	= right ascension of ascending node (degrees)
`EEEEEEE`	= eccentricity (decimal point implied such that 0.eeeeeee)
`WWW.WWWW`	= argument of perigee (degrees)
`AAA.AAAA`	= mean anomaly (degrees)
`MM.MMMMMMMM`	= mean motion (revolutions per day)
`RRRRR`	= 5 digit revolution number (leading zeroes are shown for 4 digits or less)

10.1.5 RUK12 INPUT FILES

The RUK12 orbit model accepts an osculating, Cartesian state vector as input. Although the components of the input state vector for this type of orbital element set are well-defined, the orbital element set file does not have a fixed native format for those components. The input file format for the RUK12 orbit propagation model that is used in OATS is as follows:

first data line :

x	= x position component in kilometers (real)
y	= y position component in kilometers (real)
z	= z position component in kilometers (real)

second data line

xdot	= x velocity component in kilometers (real)
ydot	= y velocity component in kilometers (real)
zdot	= z velocity component in kilometers (real)

third data line

year	= epoch year (real)
month	= epoch month (real)
day	= epoch day (real)

fourth data line

hours	= epoch hours (real)
minutes	= epoch minutes (real)

seconds = epoch seconds (real)

fifth data line

frame flag = integer flag specifying ECI (0) or ECF (1) coordinates

sixth data line

step = step size in seconds for the numerical integrator (real)

10.1.6 J2 INPUT FILES

The J2 orbit model accepts mean Keplerian orbital elements as input. Although the components of the input state vector for this type of orbital element set are well-defined, the orbital element set file does not have a fixed native format for those components. The input file format for the J2 orbit propagation model that is used in OATS is as follows:

first data line :

a = semi-major axis in kilometers (real)

e = eccentricity (real)

i = inclination in degrees (real)

second data line

Ω or α = argument of the ascending node in degrees (real); see fifth data line

ω = argument of perigee in degrees (real)

m or t = anomaly in degrees (real); see fifth data line

third data line

year = epoch year (real)

month = epoch month (real)

day = epoch day (real)

fourth data line

hours = epoch hours (real)

minutes = epoch minutes (real)

seconds = epoch seconds (real)

fifth data line

frame flag = integer flag specifying ECI (0) or ECF (1) coordinates; if ECI, α is right ascension of ascending node; if ECF, Ω is longitude of ascending node

anomaly flag = integer flag specifying mean anomaly **m** (0) or true anomaly **t** (1)

Charlie OLES

86622.6320071.8394858.00083.0002540.5181203.1292462.2360780940210

Z OLES

86622179116320071683948580000830002540651812037129246262360780292021O

PME OLES

7103986761939827786320180000401944342019794358508556617619751203300000

SGP4 TLES

```
1 88888U           80275.98708465  .00073094  13844-3  66816-4 0      8
2 88888  72.8435 115.9689 0086731  52.6988 110.5714 16.05824518   105
```

RUK12

```
      2000.19700000000       -6226.44500000000        2912.33600000000
      2.63547270000000        3.55260630000000        5.88467380000000
    1991.0000000000000       11.0000000000000         10.0000000000000
      7.00000000000000       40.0000000000000          0.000000000000000
             0
     60.0000000000000
```

J2

```
      6700.00000000000       2.000000000000000D-02    35.0000000000000
    0.000000000000000        50.0000000000000          5.00000000000000
    1993.0000000000000       11.0000000000000          1.00000000000000
    0.000000000000000        0.000000000000000         0.000000000000000
             1           1
```

Figure 10-1. Sample Orbital Element Data Files

10.2 EPHEMERIS FILES

Ephemeris files generated by OATS contain header data followed by a consecutive listing of satellite state vectors (position+velocity) separated by a constant time increment. The files are ASCII character format with a sequential organization. If a user wishes to use an OATS ephemeris file in another application, it is necessary only to use an editor to strip off the header lines. The header is not a constant length--it will be two or three lines depending upon the orbit propagator used to generate the file. Header lines are easily recognized because they begin with the character field "OATS". The header allows the OATS software to access the ephemeris data more quickly; however, it is not a requirement for the ephemeris file to have a header for OATS to access an ephemeris. Ephemeris files generated by external software can be utilized if it has a constant time increment between state vectors, and if it follows the record format described as follows. The ECF coordinate system is described in Section 6.2. Each record contains the following space-delimited fields:

YYYY	= Year (integer)
MM	= Month (integer)
DD	= Day (integer)
hh	= Hour (integer)
mm	= Minutes (integer)
seconds	= Seconds (real)
x	= ECF x-position component in kilometers (real)
y	= ECF y-position component in kilometers (real)
z	= ECF z-position component in kilometers (real)
xdot	= ECF x-velocity component in kilometers/second (real)
ydot	= ECF y-velocity component in kilometers/second (real)
zdot	= ECF z-velocity component in kilometers/second (real)

10.3 TARGET FILES

The target input file allows the user to import a list of target positions into OATS for coverage analysis and provides a means to access multiple lists of targets for different types of analysis. A target file may be created by the user using any text editing program, or may be compiled using the OATS target interface and saved to a file using the *Save* option (see Section 7.2.5). The files are ASCII character format with a sequential organization. Each record must contain the data fields as shown below, with data fields delimited by at least one blank character. Target names may be any 32-character alphanumeric string--they may be as simple as a number identification or may even be left blank provided the length is preserved in

the file. Target names are not required to process targets within OATS, because a unique target is defined by a combination of all four data fields. The user is cautioned, however, that the interface used to display targets employs standard Macintosh scrollable windows that use the title to show the existence of a data entry in the list. Targets with blank names can be processed, highlighted, and manipulated in such lists, but it is extremely awkward to differentiate between members of a list with blank name fields. Coverage analysis printouts may also be confusing.

Name = target name, any 32-character alphanumeric string
Latitude = target geodetic latitude in degrees
Longitude = target longitude in degrees
Altitude = target height above the geoid in kilometers

10.4 GROUND STATION FILES

The ground station input file allows the user to import a list of ground station positions into OATS for coverage analysis and provides a means to access multiple lists of ground stations for different types of analysis. A ground station file may be created by the user using any text editing program, or may be compiled using the OATS ground station interface and saved to a file using the *Save* option (see Section 7.2.6). The files are ASCII character format with a sequential organization. Each record must contain the data fields as shown below, with data fields delimited by at least one blank character. Ground station names may be any 32-character alphanumeric string--they may be as simple as a number identification or may even be left blank provided the length is preserved in the file. Ground station names are not required to process ground stations within OATS, because a unique ground station is defined by a combination of all five data fields. The user is cautioned, however, that the interface used to display ground stations employs standard Macintosh scrollable windows that use the title to show the existence of a data entry in the list. Ground stations with blank names can be processed, highlighted, and manipulated in such lists, but it is extremely awkward to differentiate between members of a list with blank name fields. Coverage analysis printouts may also be confusing.

Name = ground station name, any 32-character alphanumeric string
Latitude = ground station geodetic latitude in degrees
Longitude = ground station longitude in degrees
Altitude = ground station height above the geoid in kilometers
Elevation Mask = ground station elevation mask in degrees above horizon

10.5 MAP FILES

OATS contains two internal map data bases which are adequate for the majority of map plotting functions for which OATS is expected to be utilized; however, OATS also provides the user the option of supplying his own map file for special mapping projects. A user's external map file should be in sequential ASCII format, and should be organized as a set of ordered data points that define geographic outlines in a "connect-the-dots" fashion. Record format is as defined below, with each data field being delimited by one blank character. Maps are plotted with the assumption that the basic global background is an ocean globe upon which other areas with defined outlines are added. These added areas may be presented as merely outlines, or plotted as solid areas (see Section 7.3) to simulate a photographic world map. In order to achieve a "world view" map, the added areas must be classified as land masses (continents or islands) and water masses contained wholly within land masses (lakes). The record format provides a flag for discriminating between the two area types. Such outline areas would most commonly be provided for continental boundaries, large bodies of water, and major islands; however, the format does not preclude use of a map file with geo-political outlines. The use of visible vs. invisible outlines allows solid areas to be plotted side-by-side without showing boundaries in an outline map (see Section 7.3). Latitude is expressed in radians from $-\pi$ to π and longitude is expressed in radians from 0 to 2π. A negative longitude value is used as a flag to signify the start of a new plot area.

Latitude = geodetic latitude in radians

Longitude = geodetic longitude in radians (negative value is a flag; see above)

Area Type Flag = a 1-character flag showing the area type

"G" = ground area, with visible outlines

"L" = lake area, with visible outlines

"g" = ground area, with invisible outlines

"l" = lake area, with invisible outlines

10.6 CONTOUR LEVEL FILES

These files are used to store levels for either the line contouring function or for the density contouring function. It is strongly recommended that users use the OATS density interface to enter levels and colors and then do a *Save* to create a levels file (see Section 7.2.8); however, it is possible for experienced Macintosh users to create their own levels file externally. Files are very simple in format, with a sequential ASCII format and one contour level per record. Levels are usually real number type data. They should be stored as character data, should not be negative, and should be sorted in ascending order by level value. Three integer numbers follow the contour level to record the colors used for density contours; otherwise, all

color values will be read from the file as zero valued which will result in all black density contours. Color level integers should lie between 0 and 65,535. Level and color numbers should be delimited in each record by at least one blank character.

10.7 CONTOUR FILES

The OATS graphical coverage functions (see Section 8.2) create a tabular file of data which is then used to plot coverage isochrones or a color-coded density map of satellite coverage. This tabular file of data, or contour file, is usually written in a condensed version to save storage space; however, it can also be saved in expanded character format for transport to other analytical programs or direct inspection by the user. If saved in expanded form, the file will be in sequential ASCII format and will consist of one line of header data followed by a number of data records dependent on the mesh size used by OATS to perform the graphical coverage run. The header record will have a character recognition string for OATS internal usage followed by two integers, **K** and **L**. These integers identify the number of latitude and longitude grid points in the coverage computation mesh. If **N** is the user selected grid spacing in degrees of latitude, then the number of grid elements on each meridian is **(L+1)** and:

```
L = 180 / N
```

Likewise, if **M** is the grid spacing in degrees of longitude, then the number of grid elements on each parallel is computed:

```
K = 360 / M
```

The remainder of the file beyond the header is made up of the **K*(L+1)** data records representing the grid points. The grid points can be mapped back to the latitude/longitude grid via the following algorithm:

For the pth record in the file (after the header record):

```
latitude  = i * 180 / L - 90          (in degrees)
longitude = (j- 1) * 360 / K          (in degrees)
```

where

```
i = INTEGER((p-1)/K)
j = p-(i*k).
```

and the `INTEGER` function converts a real number to an integer value with truncation.

Each individual coverage record will consist of five values representing the coverage level at its point in the mesh. In left-to-right order these data are:

- Cumulative coverage as a percentage of time
- Cumulative coverage as an average daily coverage (in minutes)
- Cumulative coverage as a total daily coverage value (in minutes)
- Average cover outage (minutes per day)
- Maximum cover outage (minutes per day)

OATS contouring functions can also be used to plot data created by an external program, and which is not necessarily related to satellite coverage. An artificial contour file can be created as an input to OATS for this process. In this case, the header record in the data file to be contoured should consist of only the integers **K** and **L** as defined above. This type of header will not have the OATS recognition character string, which identifies for OATS that the file is externally created. The remaining **K*(L+1)** records to be contoured in the file should contain only one data value in ASCII character format. It is suggested that records can be created by the external software using the following pseudo code:

```
Do for longitudes j = 1,2, ..., (L+1)
    Do for latitudes i = 1,2, ...,K
        write contour value for latitude j and longitude i
    End Do
End Do
```

SECTION 11 - OATS FAST-START: SAMPLE PROBLEMS

OATS is an analytical environment. It is also very much a Macintosh-style program in that there is no straight-through "in one end and out the other" linear processing of data. The order and fashion in which the menus and processes are exercised are limited only by the user's requirements and imagination. Because of the wide-ranging scope of OATS and because of its non-linear nature, it is not possible to present a comprehensive set of examples of all procedures and outputs of which OATS is capable. This section, however, will attempt to show a few practical, typical examples of the use of OATS and the results that should be expected. The examples are presented as a sample introductory session that is written for the beginning user to follow along and to use to duplicate known results. In the course of this training exercise the user can gain some familiarity with basic functions, but note that not all important capabilities are presented.

Through the discussion of these introductory examples, most menu selections will involve sub-menu choices. As a shorthand representation, these menu selections will be shown:

Menu/Sub_Menu_Level1/Sub_Menu_Level2

11.1 SETTING THE ENVIRONMENT

After opening the OATS program from the Macintosh window, the OATS Graphics Window should appear as the only open program window. It is now referred to as the active window. Although the environment settings used in the distribution version of OATS should be functional as initial values for all users, most users will want to maximize the Graphics Window. Using the menu selection of **Window/Graph Setup** will bring up the dialog shown in Figure 5-14. Pushing *Screen Size* will automatically set the window to the same size as your primary display screen and maximize the window. However, since it is recommended that OATS be used with a square window, the user should choose the smaller value of *width* or *height* and set both *width* and *height* to this value. Verify that *Pages* settings are 1 by 1. Push the *Apply* button to make the new window sizes active, and *OK* to exit the dialog. A drag box appears in the lower right hand corner of the Graphics Window. The user should use the cursor to click-and-grab the window corner and stretch it to its maximum height and width. To save these settings, select the **File/Save Settings** menu selection and respond in the affirmative when asked to verify that an update is desired. The screen should appear as shown in Figure 3-1, and the window should be square.

11.2 CREATING AN EPHEMERIS FILE

Since OATS is an ephemeris-driven program, the first order of business is usually to construct an ephemeris file. Making the menu selection of **Propagate/Select Model/J2** will bring up the dialog shown in Figure 6-7. All data fields should be set to zero, except for the epoch. Note that 1970 is the zero-point in the time scale used by OATS routines. Pushing the *File* button will bring up the standard Macintosh file interface, which can be used to locate and select (highlight) the file called J2_ORBITAL_ELEMENTS which has been provided with the OATS program as a sample orbital elements file. Selecting *OPEN* from this standard dialog will return the user to the J2 propagator dialog, which should appear with all orbital elements set as shown in Figure 11-1.

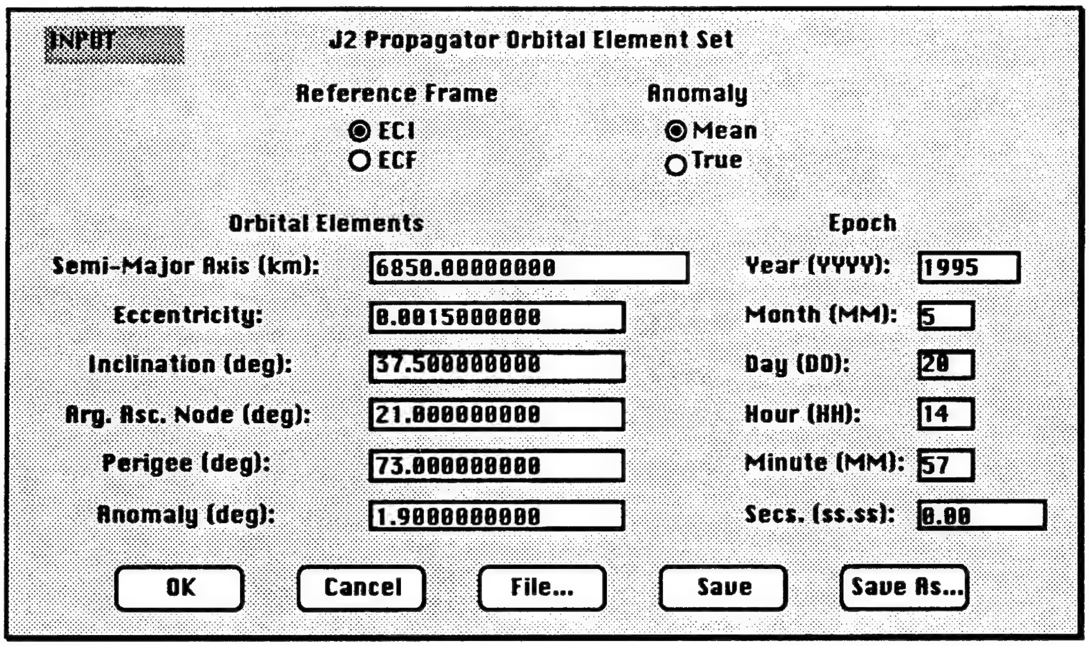

Figure 11-1. Example Orbital Elements Dialog with Elements in Place

Pushing the *OK* button will bring up the dialog shown in Figure 6-11, which is used to set the ephemeris interval. The *Start Time* will already be set to the *Epoch* used in the orbital elements. Selecting the radio button *Start Time & Number of Revolutions* will make the *Number of Revolutions* active. This parameter should be set to 1.0 for this example. *Step Size* should be set to 30.0, and the user should also push *Show Conversion* to verify the *Stop Time*. The result should show an interval running from 5-20-1995 at $14^{h}57^{m}0.00^{s}$ to 5-20-1995 at $16^{h}31^{m}2.18^{s}$. Figure 11-2 shows the expected appearance of the interval dialog after the conversion button has been clicked. Selecting *OK* will return the user to the main menu. At this point, all preparations to generate an ephemeris have been completed.

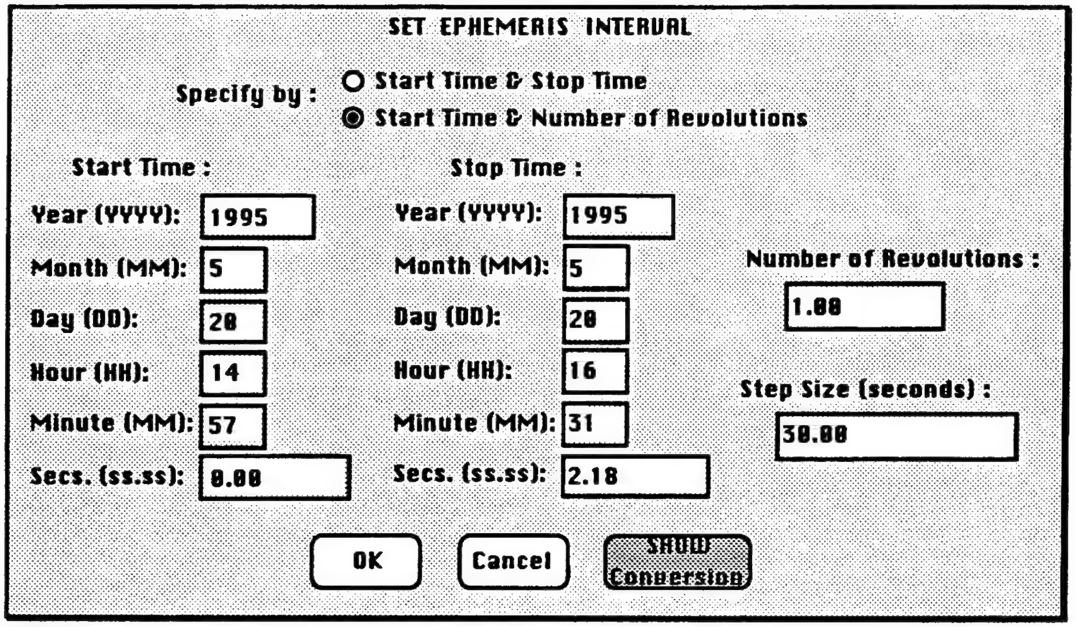

Figure 11-2. Example Ephemeris Interval Dialog with Selections in Place

Select **Propagator/Run Propagator** to initiate ephemeris generation. The Macintosh standard file interface will appear to allow the user to select a location and name for the *New Ephemeris File*. For this example, call the file J2_USER_EPHEMERIS and select *SAVE* to begin the file generation. A progress display graphic will be presented showing the file name, a tabular value of percentage of file completed, and a fill-bar graphic showing progress toward completion. When file generation is completed, the graphic will disappear and the program will return to the main menu. The ephemeris file which is generated will appear as in Figure 11-3. Note that the middle portion of the file has been deleted for brevity.

11.3 PLOTTING AN EARTH MAP

Before plotting a map to use as a background for a plot of satellite orbit characteristics, parameters defining the map must be set in two interface dialogs. The first defines the map projection and is shown in Figure 7-29. The map projection is the mathematical model that translates a three-dimensional globe onto a two-dimensional screen and defines an overview appearance of the map. The projections dialog is entered with the menu selection of **Plot/Map/Projections**. For this example, set the radio button for a *Rectangular* plot and the limits such that:

```
Min. Lat.   =   -90        Max.Lat.    =   90
Min. Long.  =     0        Max.Long.   =  360
```

```
OATS KEP1995 5201457 0.001995 5201631 0.0012_USER_EPHEMERIS          24-JAN-9515:48:22   30.00      189

OATS  0 0 1995  5 20 14 57 0.00  0.685000000000000E+04   0.0015000000000

OATS   37.5000000000000  21.0000000000000  73.0000000000000   1.9000000000000

1995  5 20 14 57  0.00   5452.504108   -943.844558   4020.108461    0.342334    7.134213    1.211314

1995  5 20 14 57 30.00   5460.184942   -729.070006   4054.255524    0.170426    7.164276    1.060108

1995  5 20 14 58  0.00   5462.708078   -513.500947   4083.838209   -0.001554    7.187074    0.907699

1995  5 20 14 58 30.00   5460.058814   -297.356039   4108.823269   -0.173443    7.202580    0.754276

1995  5 20 14 59  0.00   5452.257297    -80.854595   4129.182657   -0.345081    7.210778    0.600006

1995  5 20 14 59 30.00   5439.308507    135.783648   4144.898557   -0.516308    7.211657    0.445066

1995  5 20 15  0  0.00   5421.227246    352.338754   4155.938411   -0.686961    7.205214    0.289628

1995  5 20 15  0 30.00   5398.083117    568.590822   4162.304987   -0.856883    7.191454    0.133870

                  . . .            . . .            . . .            . . .

                  . . .            . . .            . . .            . . .

1995  5 20 16 29  0.00   4219.435842  -3756.121806   3856.220857    3.710341    5.970412    1.753604

1995  5 20 16 29 30.00   4328.876975  -3574.988833   3906.760553    3.577582    6.091017    1.608225

1995  5 20 16 30  0.00   4434.280064  -3390.226813   3952.901923    3.441335    6.205394    1.461084

1995  5 20 16 30 30.00   4535.542213  -3202.174557   3994.592986    3.301724    6.313431    1.312198

1995  5 20 16 31  0.00   4632.564344  -3010.974194   4031.786795    3.158879    6.415019    1.161884
```

Figure 11-3. Example Generated Ephemeris File

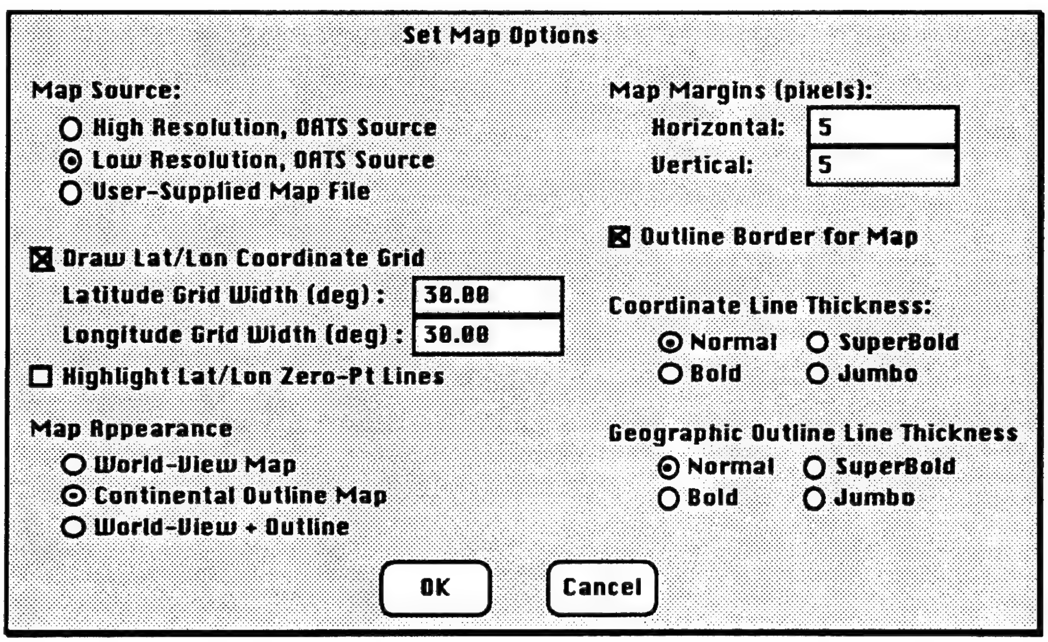

Figure 11-4. Example Map Plot Options Dialog with Selections in Place

Exit from this dialog with an *OK*, and choose **Plot/Map/Options** to open the dialog shown in Figure 7-32. The options displayed in this dialog allow the user to select a variety of details defining the map appearance. For this example, the options are set as shown in Figure 11-4. Upon exiting the options dialog with an *OK*, the user is returned to the main menu. The map is plotted by selecting the menu command **Plot/Map/Plot Map**. The resulting map is shown in Figure 11-5.

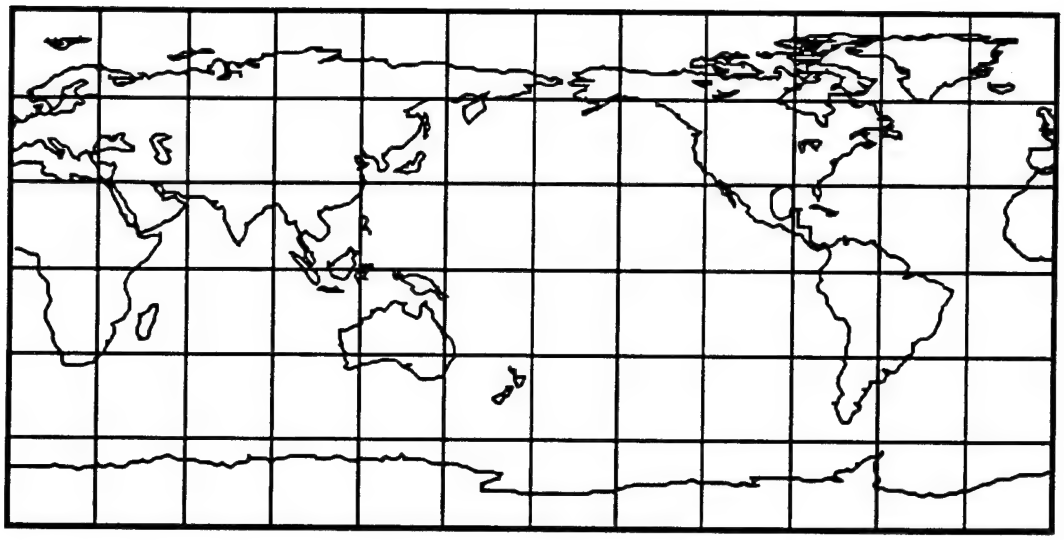

Figure 11-5. Example Map Plot

11.4 PLOTTING GROUND STATIONS

Since satellite coverage is often linked to the existence of a ground station, the next step in this quick start exercise is to plot ground stations on the map. OATS is supplied with a short list of sample ground stations in the file SAMPLE_GS_FILE. These can be accessed with the menu selection of **Plot/Ground Station Position/Options**, which brings up the interactive interface shown in Figure 7-16. There is a great deal of depth to this dialog, and the user is referred to Section 7.2.6 for details. For this introductory exercise, two ground stations will be plotted. *Open File* brings up the standard Macintosh file interface. Locate the SAMPLE_GS_FILE, highlight it, and press *Open*. This returns you to the OATS dialog, with the list of ground stations in the *Cataloged G.S. List*. Highlight "Maui", click on *Select*, and note that Maui is copied to the *Active G.S. List*. Repeat this process for the Aerecibo station. Verify that *Plot GS Names* and *Erase Name Background* are both checked. Also verify that the *GS Icon Size* is set to a value of about 8 pixels. Before exiting the dialog, it should appear as shown in Figure 11-6. Select *OK* to exit from the dialog to the main menu. At this point, use the menu selection of **Plot/Ground Station Position/Plot** to produce a plot of the Maui and Aerecibo ground stations on the original map. The result will appear as in Figure 11-7.

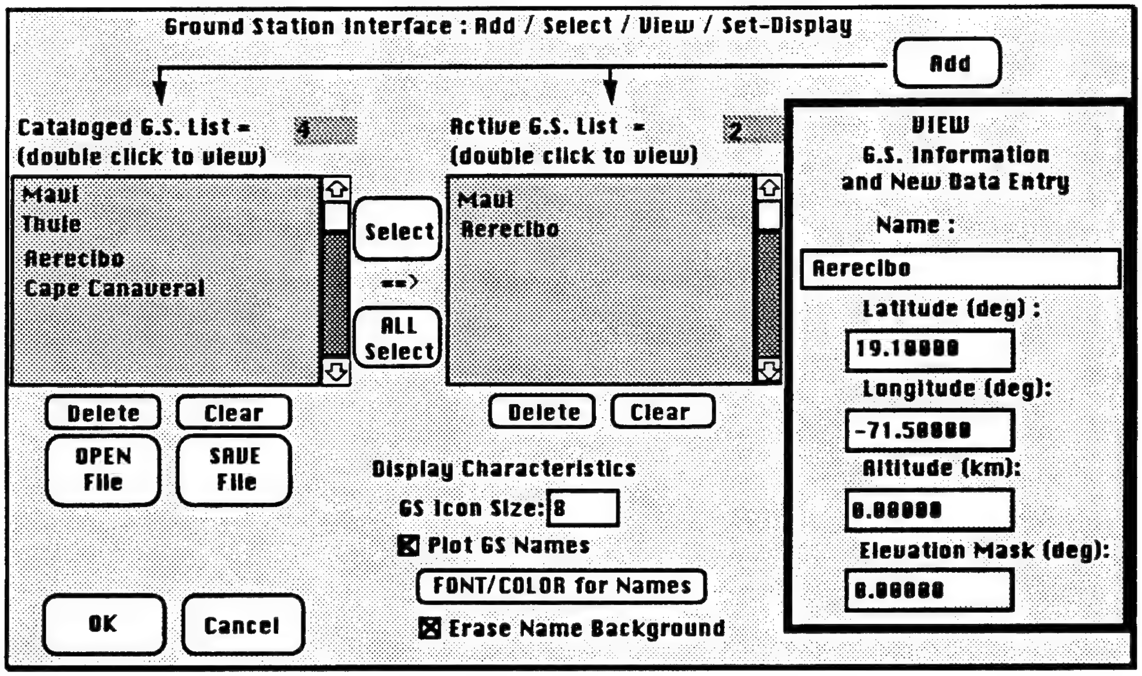

Figure 11-6. Example Ground Station Position Dialog with Two Active Stations

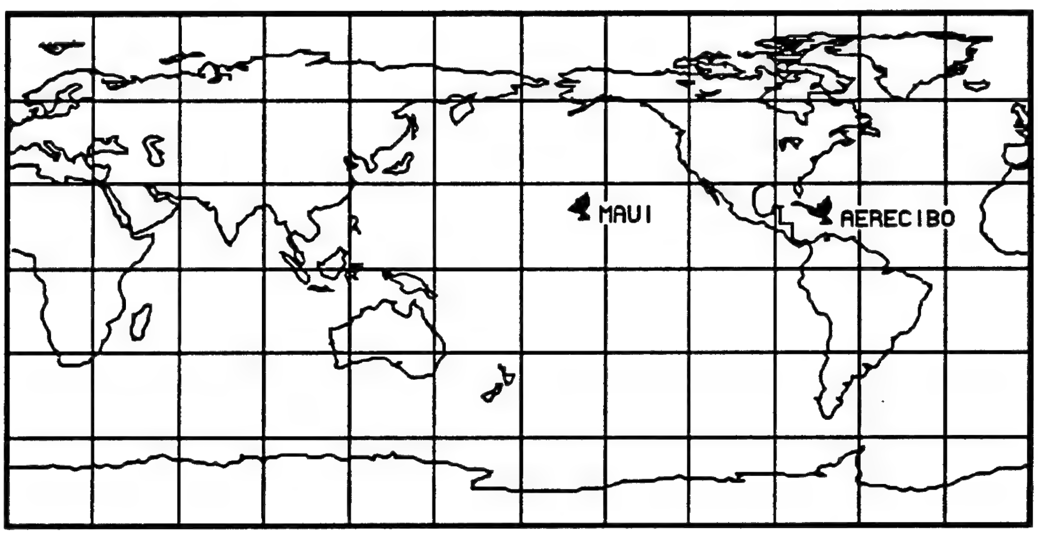

Figure 11-7. Example Map Plot with Ground Stations

11.5 PLOTTING SATELLITE TRACK

OATS provides options for plotting satellite position, FOV, track, and swath. These procedures are generally similar, so only a satellite track will be plotted in this example. Selecting the **Plot/Satellite Tracks/Options** from the OATS menu system will bring up the dialog for tracks shown in Figure 7-5.

Only one file will appear in the *Ephemeris File List*, the J2_USER_EPHEMERIS file which was created in Section 11.2. The track interval will be taken from this file, with a *Start Time* of 5-20-1995 at $14^h57^m0.00^s$ and a *Stop Time* of 5-20-1995 at $16^h31^m0.00^s$. Since the *Map* projection is Rectangular, all controls for the *Space Track* will be inactive. Ground track *Line Thickness* should be set to *Normal* and the control slide for *Line Density* should be moved all the way up to *Solid*. The *Tick Marks* checkbox should be marked to turn on the ticks, and the *Interval Size* should be set at 180 seconds with a *Tick Size* of about 3 pixels. Exiting this dialog with an *OK* will return the user to the main menu. At this point, use the menu selection of **Plot/Satellite Tracks/Plot** to add a plot of the satellite ground track to the map. The result will appear as in Figure 11-8.

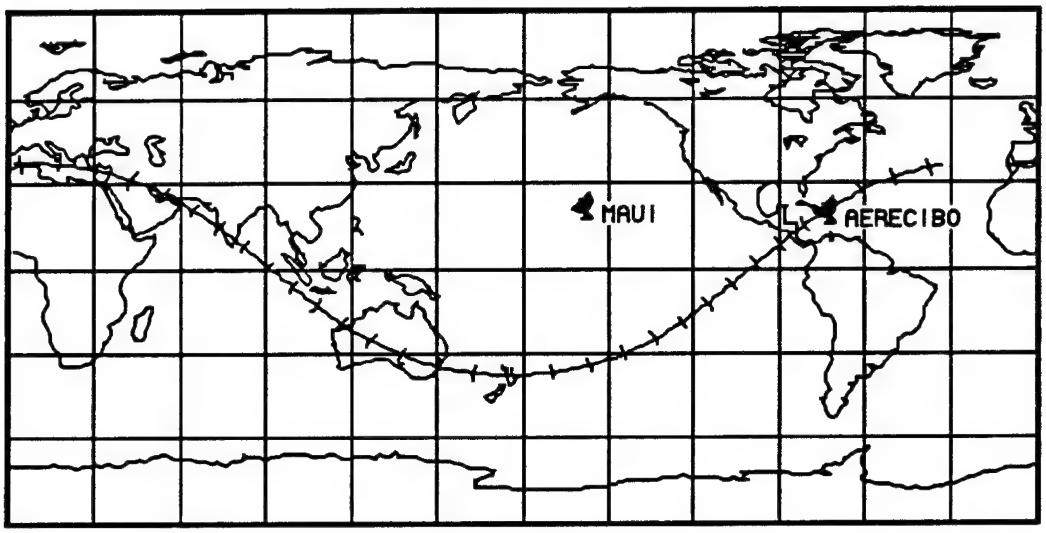

Figure 11-8. Example Map Plot with Satellite Track

11.6 COMPUTING TABULAR COVERAGE

The tabular coverage function computes satellite coverage for a system of satellites against a set of ground targets, with ground station visibility used as an optional coverage constraint. In this example, the single ephemeris file and the two ground stations already selected will be used. Tabular coverage results are saved as an output file and are presented to the user in the Tabular Output Window. In order to open this window and make it the active window (place it in front of all others), make the menu selection **Window/Tabular Output**.

Before executing the command to compute tabular coverage results, it is necessary to visit three dialogs and set required parameters. The menu selection of **Coverage/Tabular/Edit Ground Stations** will bring up the same dialog viewed when plotting ground stations (see Section 11.4). Since the Maui and Aerecibo stations have already been selected as part of a previous exercise, no further action is required

here. The **Coverage/Tabular/Edit Antennas** menu selection will bring up the dialog shown in Figure 8-3. This dialog allows the user to assign an *Antenna Type* to each satellite ephemeris file in the active list. In this example there is only one satellite and, therefore, only one ephemeris file and one antenna. Antenna types are explained in Appendix A. For this example, the radio button for a *Cone* angle antenna should be set and an angle of 75 degrees should be typed into the *Antenna Primary Angle*. The *Antenna Secondary Angle* will not be defined for a cone angle antenna and is deactivated. The checkbox for *Ground Station Constraint* should be set so that the satellite must be simultaneously in view of a target and a ground station in order to satisfy the conditions for coverage. Exit with an *OK*, then use the **Coverage/Tabular/Edit Targets** menu selection to bring up the dialog shown in Figure 7-13. The form and function is very similar to that for the ground station dialog. OATS is supplied with a short list of three sample targets in the file SAMPLE_TARGET_FILE. *Open File* brings up the standard Macintosh file interface. Locate the file, highlight it, and press *Open*. This returns you to the OATS dialog, with the list of targets in the *Cataloged Target List* Click on *Select All* and note that all four targets are copied to the *Active Target List*. Select *OK* to exit from the dialog to the main menu.

Now that the initial parameters are set, use the menu selection of **Coverage/Run Tabular** to initiate a tabular coverage run. The dialog shown in Figure 8-4 will appear. The *Start Time* and *Stop Time* for the J2_USER_EPHEMERIS will already be entered into the dialog. Set the *Step Size* at 30 seconds and mark both checkboxes to *Print Up/Down Times* and to implement *Atmospheric Refraction Correction*. Select *OK* to start the tabular coverage computation run. The Macintosh standard interface will appear, asking for a name for the *Tabular Output File* of coverage data. Enter USER_TABULAR_FILE and click on the *Save* button. The results seen in Figure 11-9 will appear in the Tabular Window and in the user-designated file.

All parameters involved in the tabular coverage run will be repeated in the header data. In this example, TARGET1 shows zero coverage because it lies outside the area viewed by the satellite. TARGET3 also shows zero coverage even though it is within the area seen by the satellite, because no ground station is within view. TARGET2 is covered by the example satellite, and shows single rise (UP) and set (DOWN) times for the pass in the J2_USER_EPHEMERIS file. All coverage values are represented by abbreviations, where:

For coverage time, the interval between AOS and LOS:

NCOV	-	Number of intervals covered (in view)
COVMIN	-	Coverage time minimum in any pass (in minutes)
COVMAX	-	Coverage time maximum in any pass (in minutes)
COVAVG	-	Coverage time average of all passes (in minutes)

COVSTD	-	Coverage time standard deviation for all passes (in minutes)
COVTOT	-	Coverage time total of all passes (in minutes)
AVGCOV	-	Average daily coverage time for ephemeris interval (minutes per day)
PCTCOV	-	Percent of time covered

For outage time, the interval between LOS and AOS:

NOUT	-	Number of intervals not covered (out of view)
OUTMIN	-	Outage time minimum (in minutes)
OUTMAX	-	Outage time maximum (in minutes)
OUTAVG	-	Outage time average (in minutes)
OUTSTD	-	Standard deviation in outage time (in minutes)
OUTTOT	-	Outage time total (in minutes)
AVGOUT	-	Average daily outage time for ephemeris interval (minutes per day)

For revisit time, the interval between one AOS to the next AOS:

NREV	-	Number of times revisited
REVMIN	-	Revisit time minimum (in minutes)
REVMAX	-	Revisit time maximum (in minutes)
REVAVG	-	Revisit time average (in minutes)
REVSTD	-	Standard deviation in revisit time (in minutes)
REVTOT	-	Revisit time total (in minutes)

11.7 CREATING A GRAPHICAL COVERAGE FILE

The graphical coverage function computes world wide coverage on a global grid for a system of satellites and ground stations. Satellites may operate out of view of the ground stations or they may be constrained to operate only while in view of a ground station. Graphical coverage analysis is done using a computed coverage file as an intermediary. In order to create this file, it is necessary to visit three setup dialogs and set required parameters. The menu selection of **Coverage/Graphical/Edit Ground Stations** will bring up the same dialog viewed when plotting ground stations (see Section 11.4) and when computing tabular coverage. Likewise, the menu selection of **Coverage/Graphical/Edit Antennas** will bring up the same dialog viewed when selecting the antenna parameters under the computing tabular coverage function. Since these parameters were already set in the last example, no further action is required. The third setup dialog is shown in Figure 8-6, and is accessed with the **Coverage/Graphical/Edit Mesh** menu selection. The default mesh size of 5 degrees square will be adequate for this example, so *OK* can be clicked to exit the dialog.

```
Tabular Output File

DEFINE SATELLITE COVERAGE COMPUTATION

Start Time (Y,M,D,h,m,sec):  1995  5 20  14 57  0.000000

Stop Time  (Y,M,D,h,m,sec):  1995  5 20  16 31  0.000000

Time Increment:       30.000000 seconds

Computational Options --  Print Up/Down Times: YES   Atmospheric Refraction: YES

Tolerance for up/down time bisection algorithm:      0.010000 seconds

GROUND STATION(S) :   2 STATIONS

  1 MAUI                   LAT,LON(deg)  20.700 203.700  ALTIT(km)  3.060  MIN.ELEV(deg)   0.000

  2 ARECIBO                LAT,LON(deg)  19.100 -71.500  ALTIT(km)  0.000  MIN.ELEV(deg)   0.000

SATELLITE EPHEMERIS FILES :   1 FILES

  1 J2_USER_EPHEMERIS

     GS Constraint: YES    Sat. Sensor Pattern:  CONE ANGLE          75.00000 deg

TARGET SUMMARY:   3 TARGETS

      LAT(deg)  LONG(deg)  ALT(km)  Name

  1      0.00       0.00     0.00   TARGET1

  2     20.80     271.10     0.00   TARGET2

  3    -14.80     142.30     0.50   TARGET3
------------------------------------------------------------------------------

TARGET NO.  1  NAME: TARGET1                    LAT:   0.00  LON:   0.00  ALT:   0.00 KM

PASS STATISTICS (MINUTES)

UP                  DOWN              COVERAGE  OUTAGE  REVISIT

COVERAGE STATISTICS (MINUTES):

  NCOV:        0  NOUT:        1  NREV:        0

COVMIN: ******** OUTMIN:    94.00 REVMIN: ********

COVMAX: ******** OUTMAX:    94.00 REVMAX: ********

COVAVG:     0.00 OUTAVG:    94.00 REVAVG:     0.00

COVSTD:     0.00 OUTSTD:     0.00 REVSTD:     0.00

COVTOT:     0.00 OUTTOT:    94.00 PCTCOV:     0.00

AVGCOV:     0.00 AVGOUT:  1440.00 MINUTES/DAY
------------------------------------------------------------------------------
```

Figure 11-9. Example Tabular Coverage Output (1 of 2)

```
TARGET NO.   2   NAME: TARGET2                    LAT:   20.80  LON:  271.10  ALT:    0.00 KM

PASS STATISTICS (MINUTES)

UP                    DOWN                   COVERAGE  OUTAGE  REVISIT

1995  5 20 16 15  0.0  1995  5 20 16 22 46.2     7.8     78.0      0.0

COVERAGE STATISTICS (MINUTES):

 NCOV:        1  NOUT:         2  NREV:        0

COVMIN:    7.77 OUTMIN:     8.23 REVMIN: ********

COVMAX:    7.77 OUTMAX:    78.00 REVMAX: ********

COVAVG:    7.77 OUTAVG:    43.12 REVAVG:     0.00

COVSTD:    0.00 OUTSTD:    34.88 REVSTD:     0.00

COVTOT:    7.77 OUTTOT:    86.23 PCTCOV:     8.27

AVGCOV:  119.03 AVGOUT:  1320.97 MINUTES/DAY
```

```
TARGET NO.   3   NAME: TARGET3                    LAT:  -14.80  LON:  142.30  ALT:    0.50 KM

PASS STATISTICS (MINUTES)

UP                    DOWN                   COVERAGE  OUTAGE  REVISIT

COVERAGE STATISTICS (MINUTES):

 NCOV:        0  NOUT:         1  NREV:        0

COVMIN: ******** OUTMIN:    94.00 REVMIN: ********

COVMAX: ******** OUTMAX:    94.00 REVMAX: ********

COVAVG:    0.00 OUTAVG:    94.00 REVAVG:     0.00

COVSTD:    0.00 OUTSTD:     0.00 REVSTD:     0.00

COVTOT:    0.00 OUTTOT:    94.00 PCTCOV:     0.00

AVGCOV:    0.00 AVGOUT:  1440.00 MINUTES/DAY
```

Figure 11-9. Example Tabular Coverage Output (2 of 2)

The **Coverage/Run Graphical** menu selection will initiate computation of the graphical coverage file by bringing up the dialog shown in Figure 8-7. *Start Time* and *Stop Time* should already be set from the J2_USER_EPHEMERIS and *Step Size* was set in a previous dialog. After verifying that the *Data Compression* flag has been checked to keep the coverage file to a minimal size, the *OK* button should be clicked. The Macintosh standard file interface will appear, allowing the user to select a location and name

for the *New Coverage Data File*. For this example, call the file USER_COVERAGE_FILE and select *Save* to begin the file generation. A progress display graphic will be presented showing the file name, a tabular value of percentage of file completed, and a fill-bar graphic showing progress toward completion. When file generation is completed, the graphic will disappear and the program will return to the main menu.

11.8 PLOTTING LINE COVERAGE CONTOURS

Line contours showing isochrones of satellite coverage can be plotted using the coverage file created in Section 11.7. The Graphics Window should again be the active window because it is used for the progress diagnostic. If not, the menu selection **Window/OATS Graphics Window** will bring it to the front. Next select **Plot/Line Contours/Options** to bring up the line contouring options dialog shown in Figure 7-24. *Contour Levels* can be loaded quickly using the *OPEN File* button, which brings up the standard Macintosh file interface. Identify and highlight the file SAMPLE_LEVELS_LIST which is provided with the OATS program, and enter *OPEN* to return to the line contours dialog. Verify that the *Cumulative Coverage* and *Percentage of Time* radio buttons have been selected. The meaning of these coverage choices is explained in Section 7.2.9. Also verify that the *Bold* selection has been made for the *Line Thickness*, and that the *Labeling of Contour Values* is turned *ON* and that the *INTEGER Values* button has been selected. The line contours dialog has a great more depth than may be indicated from this basic example--the user is referred to Section 7.2.9 for more details. Selecting *Open Covg* returns the user to the main menu.

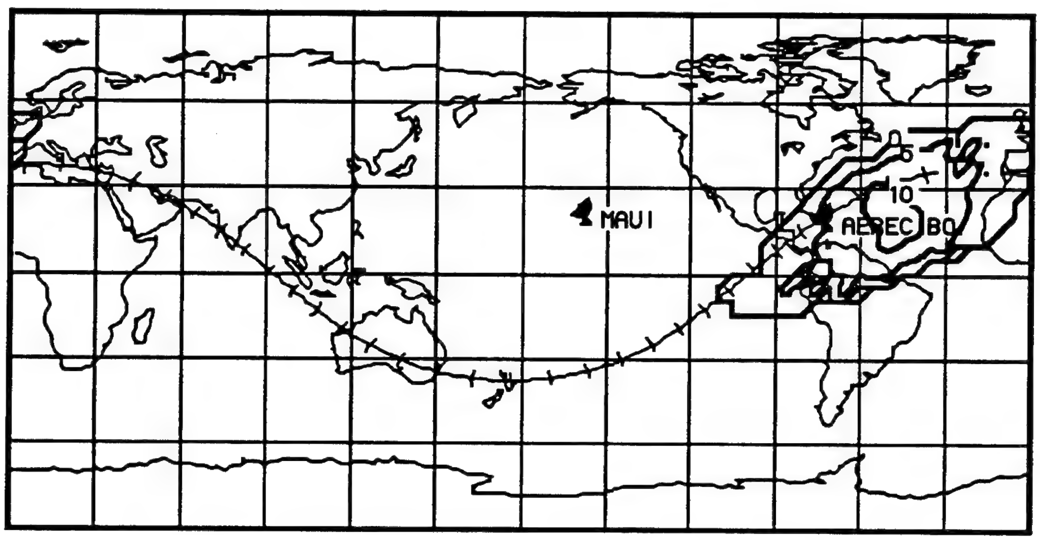

Figure 11-10. Example Map Plot with Line Coverage Isochrone Contours

Plotting of the line contours is initiated by the menu selection **Plot/Line Contours/Plot**. The Macintosh standard file interface dialog will appear, from which the user should select the

USER_COVERAGE_FILE. Clicking the *OK* will produce the line coverage diagram shown in Figure 11-10.

11.9 LOOK-ANGLE ANALYSIS

Look-angle coverage analysis is used to produce a tabular list of data describing where and when a ground station will be able to view a satellite as it passes overhead. Since this is again a tabular output, the user should use **Window/Tabular Output** to change the active window for display of the data for satellite passes. This coverage analysis also requires that initial parameters be set in three setup dialogs, but none of these is shared with the previous functions.

The menu selection of **Coverage/GS Look Angles/Select GS** brings up the dialog shown in Figure 8-9. For this example, double click on the Aerecibo station to make it active and exit with an *OK*. The **Coverage/GS Look Angles/Select Ephemeris File** menu selection would ordinarily be used to select a file to be used for analysis from the list of open ephemeris files shown in the dialog in Figure 8-10; however, in this example only one file is open so the second dialog may be bypassed. The third setup dialog is shown in Figure 8-11 and is brought up by choosing **Coverage/GS Look Angles/Set Frequencies**. It is used to set the uplink and downlink communication frequencies so that signal attenuation may be computed. In this example, the *Link Margin* flag should be turned off and the dialog exited with an *OK*.

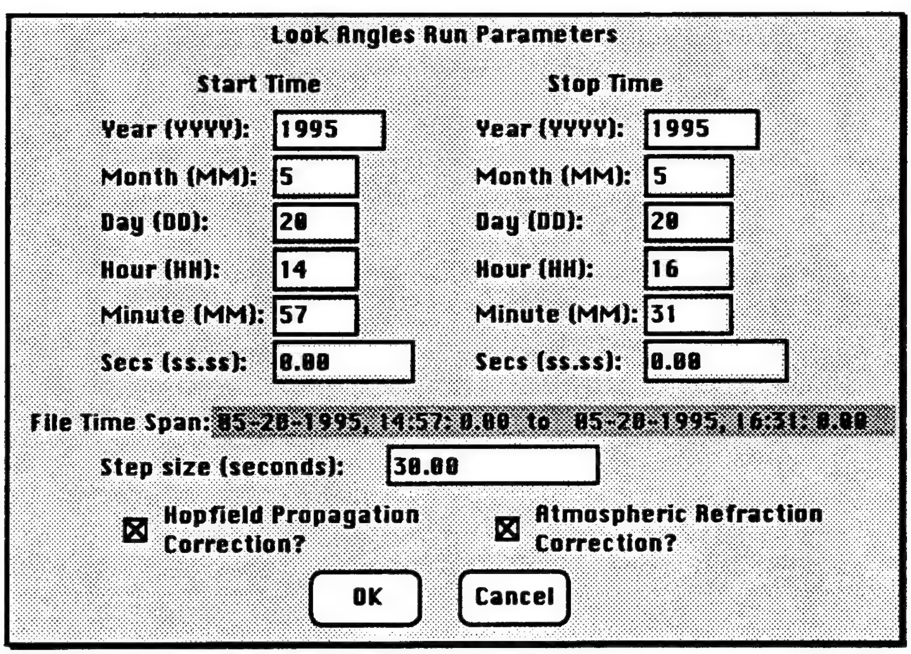

Figure 11-11. Example Look Angles Dialog with Parameters Set

The look-angles computations are initiated by selecting **Coverage/Run GS Look Angles**. The dialog shown in Figure 8-12 will be displayed. The *Start Time, Stop Time*, and *Step Size* will already be set from previous examples. The user should verify that both checkboxes are marked as shown in Figure 11-11, and exit the dialog with an *OK*. The Macintosh standard file interface will appear and should be used to assign a *Look Angles File* name for the look-angle computations. Computations will be shown in the Tabular Window and will also be echoed in the output file. Exiting the standard interface with a *Save* produces the output shown in Figure 11-12. Note that the middle sections of the output have been removed for brevity. All data relevant to the look-angle setup is displayed in the output header data.

```
Look Angles File

 COMPUTE PASS STATISTICS

 Start Time (Y,M,D,h,m,sec):  1995  5 20  14 57  0.000000

 Stop Time  (Y,M,D,h,m,sec):  1995  5 20  16 31  0.000000

 Time Increment:       30.000000 seconds

 Computational Options -- Hopfield Correction: YES  Atmospheric Refraction: YES  Link Margins: NO

 Ground Station Name : AERECIBO

   LAT,LONG(deg)  19.100 -71.500   ALTIT(km)   0.000   MIN.ELEV(deg)   0.000

 Satellite Ephemeris File: J2_USER_EPHEMERIS

    Complete Date        Azimuth Elevation    Range     RangeRate    RangeRate   Shadow AOS/

 YR  MO DY Hr Mi Secs     (Deg)    (Deg)       (Km)      (Km/Sec)      (PPM)     Status LOS

 ---- -- -- -- -- -----  -------- -------- ----------- ------------ ---------- ------ ----

 1995  5 20 16 14 38.61  241.3724  -0.0002   2549.8410   -6713.2813   -22.3928   - -  !AOS

 1995  5 20 16 15  0.00  241.7686   1.1736   2406.0691   -6708.9850   -22.3785   - -

 1995  5 20 16 15 30.00  242.3879   2.9191   2204.7245   -6694.9371   -22.3317   - -

 1995  5 20 16 16  0.00  243.1392   4.9909   2003.9777   -6668.6317   -22.2439   - -

 1995  5 20 16 16 30.00  244.0582   7.4012   1804.2649   -6625.1885   -22.0990   - -

 1995  5 20 16 17  0.00  245.2117  10.1836   1606.2107   -6556.6383   -21.8704   - -

 1995  5 20 16 17 30.00  246.7076  13.4906   1410.7554   -6449.3667   -21.5125   - -

     . . .              . . .            . . .              . . .                  . . .

 1995  5 20 16 25 30.00   50.3770   3.9104   2105.5594    6679.6904    22.2813   - -

 1995  5 20 16 26  0.00   51.0909   2.0056   2306.5416    6699.0185    22.3458   - -

 1995  5 20 16 26 30.00   51.7001   0.3802   2507.9375    6707.8274    22.3752   - -

 1995  5 20 16 26 36.42   51.8195  -0.0003   2551.0846    6708.6049    22.3777   - -  !LOS
```

Figure 11-12. Look-Angle Example Computations

REFERENCES

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8. NRL-FR-6930, "A Guide to Basic Pulse Radar Maximum Range Calculation, Part I: Equations, Definitions, and Aids to Calculation", by Blake, L.V., Naval Research Laboratory, Washington, DC, Dec. 23, 1969
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ACRONYM LIST

AOS	- Acquisition of Signal
clut	- color look-up table
ECF	- Earth Centered Fixed
ECI	- Earth Centered Inertial
FOV	- Field of View
GS	- Ground Station
LOS	- Loss of Signal
OATS	- Orbit Analysis Tools Software
OLES	- One Line Element Set
TLES	- Two Line Element Set
WGS84	- World Geological Survey 1984

GLOSSARY

command-key: designation for a Macintosh procedure initiated using a two key sequence. A command-key is implemented by pressing and holding the ⌘ key (also shown as), and then pressing another key.

coverage time: the interval between Acquisition of Signal (AOS) and Loss of Signal (LOS).

elevation mask: for a ground station, the elevation mask defines the portion of the station's hemispherical horizon not visible to the station; it is the elevation above the horizon above which a satellite must rise before it can be viewed by a ground station.

herg: a unit of time measure commonly utilized in orbital mechanics; it equals 806.8120769 seconds and is the orbital period of an imaginary satellite rotating about the Earth at zero altitude.

isochrones: lines connecting points on the Earth's surface that have equal values of time duration of satellite coverage.

marquee: a rectangular area within an open graphics window that has a moving dotted line defining the rectangles edge; the marquee defines a highlighted area within a graphics window for which some action will be initiated that does not affect the remainder of the un-highlighted area in the open window.

outage time: the interval between LOS and AOS.

revisit time: the interval between one AOS to the next AOS.

swath: the area on the Earth's surface swept out by the field-of-view of a satellite as it rotates around the planet and scans over the surface.

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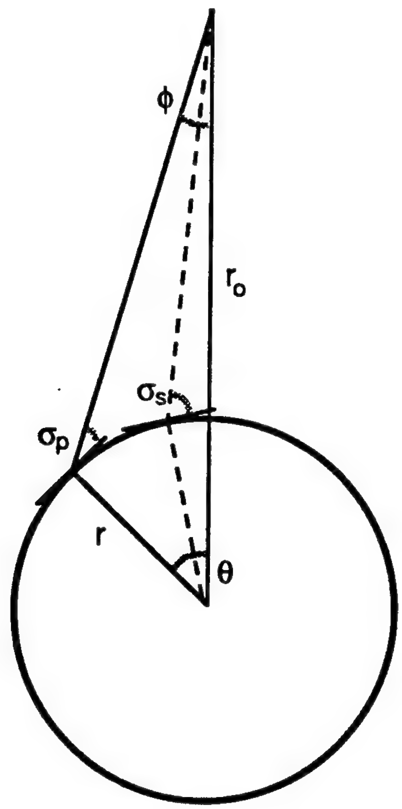
APPENDIX A - ANTENNA DEFINITIONS

Version 3 of the OATS software supports nadir viewing, conical satellite sensor patterns. OATS also supports an annular satellite field-of-view, which is a variation on the nadir-pointed conical sensor pattern wherein a nadir-pointing conical "hole" exists in the antenna's sensitivity pattern. The viewing geometry is depicted in Figure A-1.



r	=	earth radius
r_o	=	satellite orbital radius
ϕ	=	cone angle
θ	=	earth central angle
σ_p	=	primary elevation angle
σ_s	=	secondary elevation angle

Figure A-1. Satellite Antenna Pattern Geometry

Where required under the **Plot** and **Coverage** menus, the user can define the sensor pattern by selecting an antenna type of cone angle, earth central angle, or elevation angle. For these cases, a single angle defines the sensor FOV. Program dialogs designate this single angle as the primary angle, even though no other angle is necessary. Selection of an antenna type that is annular requires specification of both the primary elevation angle and the secondary elevation angle. It is required that the secondary angle be larger than the primary angle.

APPENDIX B - TIPS FOR PROCESSING WITH OATS

TIP # 1 - ADVANCED PRINTING TECHNIQUE

The Macintosh screen resolution of 72 pixels/inch is lower than what most printers can achieve. Printing a screen plot with an "as-is" resolution will result in significant granularity in the drawing. To reduce this problem and work with a higher printing resolution (more pixels per inch), the user can choose a smaller "percent reduction" (see Section 5.4). Maximum resolution and detail can be achieved with a LaserWriter (300 dpi) using a 25% reduction setting when printing. However, such a reduction can result in a hardcopy plot that is diminutive. Selective sizing of the Graphics Window that is being plotted such that it is set to be significantly larger than the display size of most monitors allows a normal sized final output page to be printed. FACEIT and OATS can work with this setup, but the user should understand that only a small portion of his oversize plot will show in the Graphics Window and that the full plot can be viewed in the Reduced View Window.

TIP # 2 - SQUARE GRAPHICS WINDOW

OATS is capable of supporting any size graphics window that can fit on the screen, but the user is advised that a square window is usually preferred. Rectangular windows are quite acceptable, and there may be some occasion (e.g. some variations on Mercator plots) where they might improve the readability of the plot. However, the user should note that non-square windows do introduce a distortion into the plots that can be confusing and which may not transport well to other applications.

TIP # 3 - PICTURE CROPPING

Maps and pictures drawn using OATS can be incorporated in other documents using the OATS **Copy Frame Area** or **Cut** menu options, and then a **Paste** in the targeted document. Sometimes during this process the map borders may be large enough that an unacceptably large amount of white space is also copied along with the map if a **Select All** is used to specify the area copied. This is commonly the case when using a rectangular map projection with a square window. To alleviate the problem, it is possible to redefine the window size and border size and redraw the map; however, it is more efficient to eliminate the white space by cropping the picture before transfer. This is done by positioning the cursor a few pixels above and to the left of the OATS map. Push and hold the Apple () key, and click and hold the mouse. Drag the cursor to a few pixels below and to the right of the map. This encloses the map being transferred in a minimized marquee, and selects this minimized area to be transferred. Then using **Copy** and **Paste** will not move the excess white space to the user's document.

APPENDIX C - REVIEW OF ORBITAL ELEMENTS

This users manual is not an appropriate vehicle for a comprehensive discussion of orbital elements or the mathematical models behind the various orbit propagators; however, the authors do furnish this section as a *basic* explanation of the terminology used to specify orbital elements. For an in-depth review of the derivations of the orbital elements, the user is directed to Reference 9. For a better understanding of the orbit propagators, see Section 6.1 and the references cited therein. The review of orbital element terminology applies throughout the document, but is especially relevant to the Section 10.1 discussion of orbital elements and the Section 6.3 discussion of the entry dialogs for orbital elements.

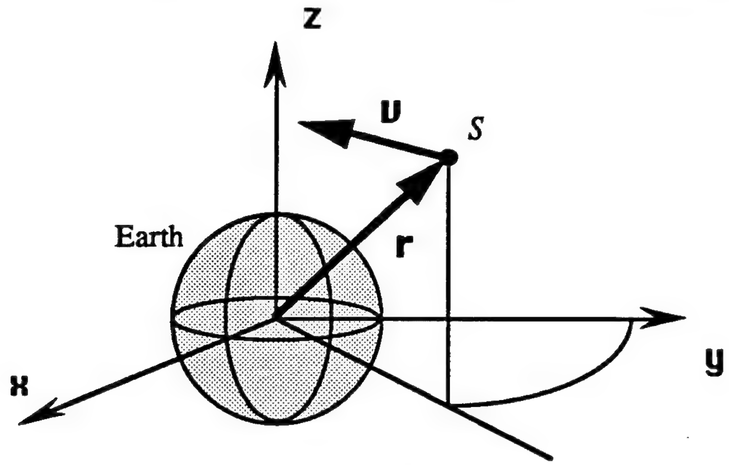


Figure C-1. Cartesian Representation of a Body in Space

The position of any satellite in space, *S* can be represented by its position vector **r**(t) as shown in Figure C-1. If **r** is represented as the sum of its three-dimensional Cartesian vector components:

$$\mathbf{r}(t) = \mathbf{x}(t) + \mathbf{y}(t) + \mathbf{z}(t) \qquad 10\text{-}1$$

then any motion of the body can be represented as the time rate of change of each of the vector components, or the velocity vector **v**(t):

$$\mathbf{v}(t) = \frac{d\mathbf{x}(t)}{dt} + \frac{d\mathbf{y}(t)}{dt} + \frac{d\mathbf{z}(t)}{dt} = \dot{\mathbf{x}}(t) + \dot{\mathbf{y}}(t) + \dot{\mathbf{z}}(t) \qquad 10\text{-}2$$

This simple formulation of orbital elements is the Cartesian state vector used by the RUK12 propagator. Orbital elements are specified by **x**, **y**, **z**, and **x**dot, **y**dot, and **z**dot at a known point in time. The RUK12 propagator then takes the known position and velocity, combines them with the equations of motion, and repetitively projects the position and velocity at some small increment of time Δt beyond the known time.

The only other factor required to specify the RUK12 orbital element set is a flag that defines if the supplied position and velocity vector components are given in the ECI or ECF coordinate frame (see Section 6.2). The difference between the two is a rotational coordinate transformation that accounts for the difference in the placement of the zero point in time. In addition to the conceptual simplicity of the orbital elements, the RUK12 propagator has an advantage over the other available propagators in that it can propagate any trajectory. These advantages are offset by the fact that this propagator is computationally intensive and much slower than the other options available.

A somewhat more common approach to the problem of specifying the orbital elements for a spacecraft is to assume that the satellite is gravitationally bound to the Earth. Such a satellite follows a closed path that is a conic section called an ellipse. This simplifying assumption transforms the problem of specification of orbital parameters to one of specification of parameters that define the geometrical shape and orientation of the ellipse. Other non-closed conic section orbits are of course physically possible (e.g. parabolic or hyperbolic paths); however, with the exception of the RUK12 propagator, OATS orbit propagators are not relevant to such orbits. There are always minor deviations from a true ellipse in a satellite orbit--deviations that are caused by real-world factors like atmospheric drag, solar radiation pressure, deviations of the Earth from a spherical shape, non-uniformities in gravitational pull on the satellite, or forces originating in the satellite itself like engine firings or outgassing. Some of the propagators available in OATS (e.g. SGP4) account for the largest of these deviations, but over time there will always be degradation of an orbit and evolution of the orbital elements. This is why every set of orbital elements is furnished with an epoch at which the elements were calculated and at which the elements are correct. The further in time that an orbit deviates from the source epoch, the larger the errors that can be expected to be found.

An ellipse is defined as the collection of points in a plane, such that for each possible point the sum of distances from two fixed points to the ellipse point is a constant value. The basic geometry of an ellipse is shown in Figure C-2. The center of the Earth will always occupy one of the defining points for the ellipse, known as a focus (F_1). The other focus (F_2) is empty, but for most real orbits this focus lies within the diameter of the Earth. The distance **AB** is the greatest diameter of the orbit, called the major axis. Both foci are equi-distant from the center **X** and located on the major axis. The distance **CD** is the smallest diameter of the orbit, called the minor axis. **AB** and **CD** are the axes of symmetry of the ellipse, and meet at the center at **X** and cross at a right angle to each other. The distance **AX** or **BX** is known as the semi-major axis, **a**. This distance is also the mean distance of the satellite from the center of the Earth at focus F_1. The stretching (or flattening) of the ellipse is measured by a unitless quantity called eccentricity, **e**. If **c** is the distance from the center to a focus, then:

$$e = c / a \quad \text{or} \quad c = a * e \qquad 10\text{-}3$$

A circular shaped orbit is merely a special case of the ellipse where $e = 0$. If S represents a satellite in Figure C-2 moving along its orbit at an arbitrary time t, then the position of the satellite can be specified by the angle f, the true anomaly.

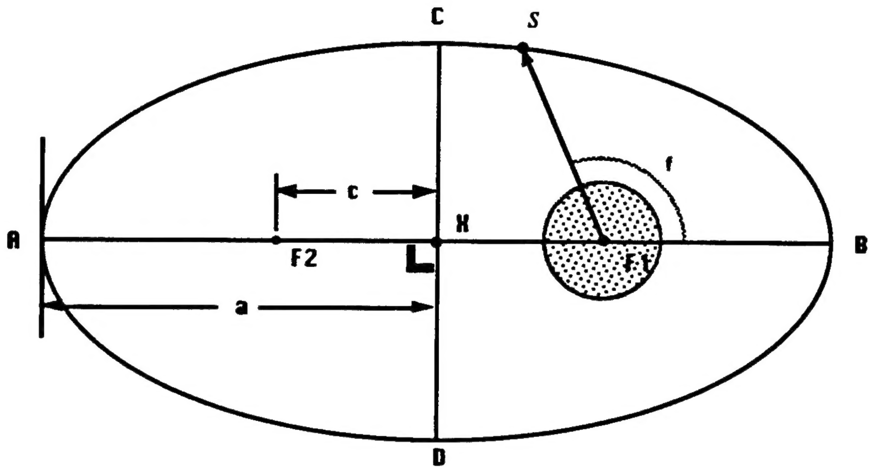


Figure C-2. Basic Geometry of an Orbit Ellipse

While the semi-major axis, eccentricity, and true anomaly are adequate to define the shape of the orbit they do not determine the spatial or temporal orientation of the ellipse relative to the Earth. The classical solution to this problem is to define three angles--an inclination i, a right ascension Ω, and the argument of perigee ω--as shown in Figure C-3.

For Figure C-3, the **xyz** Cartesian coordinate system is defined such that the **xy** plane coincides with the Earth's Celestial Equator (equatorial plane) and the **+x** axis is aligned with γ, the Vernal Equinox. Also known as the first point of Aries, γ is the point on the celestial sphere where the ecliptic (apparent path of the sun) crosses the celestial equator in the spring. The inclination angle i is the angle between the orbit plane and the Earth's equatorial plane. Inclination is measured around the line of intersection of the equatorial and orbit planes, also known as the line of nodes. This line connects the ascending node **AN** (the point on the equator where the satellite passes from the southern hemisphere to the northern) to the descending node **DN** (where the satellite passes from northern to southern). The angle Ω is the right ascension angle between the vernal equinox and the ascending node as measured in the equatorial plane. The third angle ω is the argument of perigee. It is defined relative to the perigee (perifocus), or closest approach to the central body around which the satellite is orbiting. The perigee is labeled point **B**. The argument of the perigee is the angle from the ascending node to the perigee measured in the orbital plane.

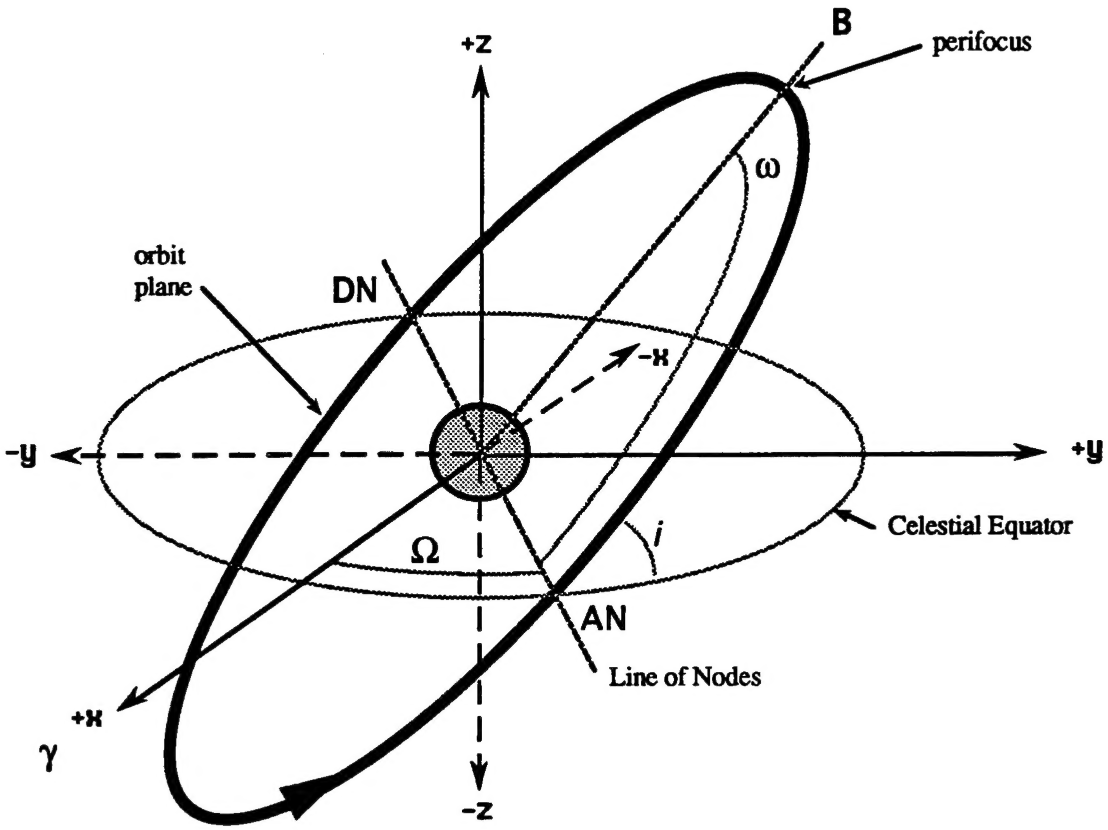


Figure C-3. Orientation of Orbit Ellipse Relative to Earth

The six coordinates of the ellipse, **a**, **e**, f, i, ω, and Ω are sufficient to completely specify an orbit, and can be used in conjunction with an epoch and a flag designating an ECF or ECI coordinate system for the orbital elements for the J2 propagator. However, these often do not represent the easiest formulation of the orbital elements to work with.

Figure C-4 presents an alternative geometrical representation of the orbit ellipse which is intended to complement the basic schematic presented in Figure C-2. In this figure, a circumscribing auxiliary circle is placed around the ellipse. **P** now designates the point of perigee. The geometry shows the auxiliary angle **E**, eccentric anomaly, which is introduced as an intermediate computational and comprehension step. Eccentric anomaly is defined as the angle measured in the orbital plane from the axis of perigee passage to a line containing the center and another point defined by the projection of the moving vehicle in the axis perpendicular to the perigee axis upon an auxiliary circle circumscribing the ellipse of satellite motion. In Figure C-4 the projection of the satellite on the circle is a fictitious satellite S_m . The mean angular rate of the satellite, called mean motion, is usually symbolized as **n**. Mean motion is the angular rate of the

fictitious satellite as it travels around the circumscribing circle. By definition **n** is an easily specified constant value, whereas the true angular rate of the satellite around an ellipse varies with position on the ellipse. The mean anomaly, **M**, is another auxiliary angle that physically represents the angular displacement of the fictitious satellite and the mean angular rate of the satellite. The quantities **n** and **M** represent the last of the orbital elements typically used as inputs for the J2, SGP4, and PPT2 propagators. Useful relations of these two quantities are as follows:

$$M = E - e * \text{sine } E \qquad 10\text{-}4$$

$$n = 2\pi/\text{period} = \sqrt{\left(\mu/a^3\right)} \qquad 10\text{-}5$$

where μ is the combined mass of the satellite and the Earth, usually rounded to just the mass of the Earth.

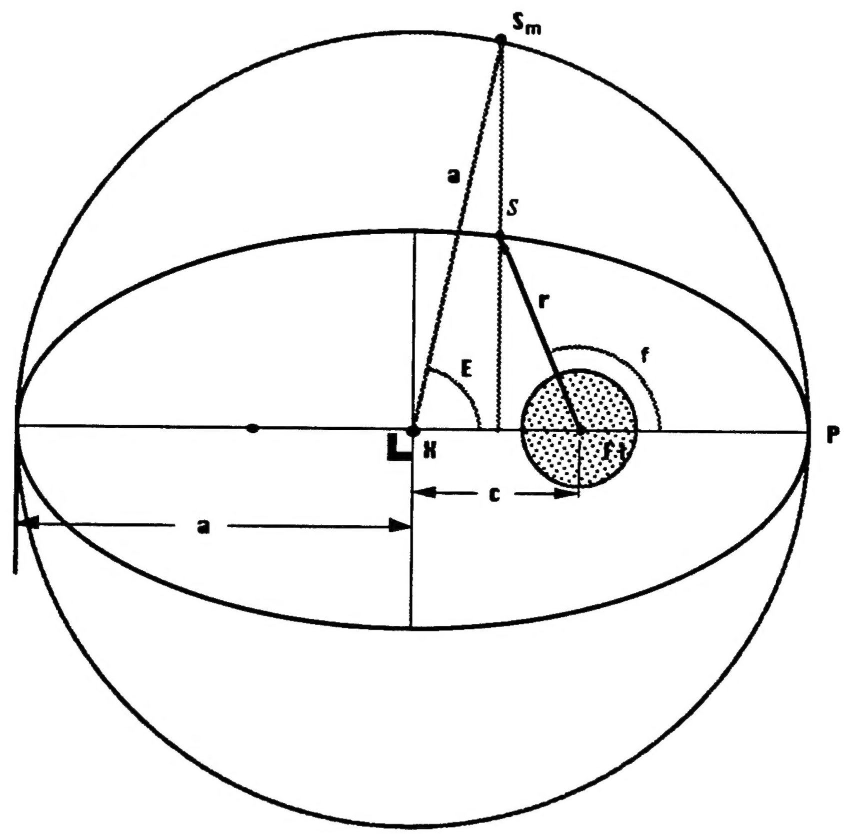


Figure C-4. Geometric Representation of Mean Motion